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ROYAL AIRCRAFT ESTABLISHMENT

Farnborough. Hants.

DRAG AND COOLING TESTS

IN THE 24 ft. WIND TUNNEL ON A

CENTAURUS-BUCKINGHAM WING NACELLE INSTALLATION

PART III.

TESTS WITH HIGH SPEED COWL ENTRY (TEMPEST TYPE)

by

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and
B. STOKES

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SUMMARY

Tests were made to determine the air flow and drag characteristics of a Centaurus-Buckingham wing nacelle installation fitted with a high velocity cowl entry, with and without a high solidity spinner fan. Flows and pressures were measured at values of J corresponding to Weak Mixture Cruise, All Out Level, Climb and ground running conditions. Flows pressures and drags were measured with propeller (and fan) removed.

The main results are given in the following table:-

/Table

	No Propeller		W.M. Cruise and A.C. Level (J = 2.2)			
			Without fan		With fan	
Gill Position	Closed	Open	Closed	Open	Closed	Open
Total head in cowl entry ÷ q	0.89	0.98	0.90	0.92		
Total head at front of cylinders ÷ q	0.79	0.76	0.84	0.76	0.92	0.75
Total head drop from front of cylinders to gill exit ÷ q	0.43	0.91	0.48	0.93	0.47	0.89
Baffle constant based on above total head drop	0.52	0.54	0.59	0.59	0.51	0.50
Baffle constant based on pressure integrating ring readings	0.43	0.49	0.54	0.53	0.49	0.47
Cooling air flow (cu. ft./sec. at 100 ft./sec.)	136	197	136	191	145	203
Drag (lb. at 100 ft./sec.						
Internal – Minimum	7.7	32.9				
Internal – Residual	4.9	17.3				
External (gill hinge gap sealed)	-2.2	9.4				
Faired body	17.2	17.2				
Power plant (excluding oil cooler)	27.6	76.8				

The addition of the fan increases the net propulsive efficiency of the engine propeller unit under all flight conditions.

In addition the maximum attainable flow is increased by 45% for ground running and 20% for climb conditions.

LIST OF CONTENTS

LIST OF APPENDICES

LIST OF ILLUSTRATIONS

1 Introduction

Details of investigations into the airflow and drag characteristics of a Centaurus-Buckingham wing-nacelle installation fitted with (a) C.T.A. exhaust system (Prototype Buckingham) and (b) rear swept exhaust system (Production Buckingham) have been given in Part I[1] and Part II[2] of this report. The present part describes tests made on the same installation as (b) but with the cowl entry and spinner replaced by a high speed cowl entry, and a spinner of $33\frac{1}{2}$" maximum diameter, as fitted to the Tempest II aircraft. The tests were made with and without a high solidity cooling fan driven at propeller speed.

2 Description of test unit

2.1 Nacelle on wing

The nacelle and wing with supporting pylon are shown in Figs.1 and 2. The important dimensions of the installation are given in Appendix I. Except for the nose cowl, spinner and propeller, these are the same as are quoted in Part II of this report. Fig.3 is a section through the power plant showing the essential features as regards airflow and also the position and type of the measuring instruments. The circumferential position of the entry and exit instruments is shown in Fig.4. The instrumentation has been considerably improved since the previous series of tests and a full description is given in Appendix II.

The new nose cowl is of the type used on the Tempest II aircraft and was designed to obtain a higher entry velocity for a given flow. The spinner diameter is 33.50 ins. and the mean entry gap 3.44 ins. giving an entry area of 2.51 sq.ft. The spinner contour is maintained back to the cylinders by a crankcase fairing. When the fan is not fitted the resulting gap is filled by a stationary fan ring. The position of the fan and the modifications to the diffuser shape when the fan is fitted are shown in Fig.5.

Control of the cooling flow is by the usual adjustable gill type of exit which is continuous round the whole circumference. The gill hinge gap was sealed over with fabric for all the flow tests.

The engine cowling gradually changes from circular at the nose cowl to oval at the gill exit. The rear swept exhaust system is described in detail in Part II of this report. Nine equally spaced groups, each of two rearward facing exhaust pipes, are fitted in the gill exit terminating level with the edge of the gill plates.

2.2 Faired body

The faired nose used for previous tests was fitted over the nose cowl and the gill gap faired over (with the gills in the closed position) to provide a datum faired body for estimating the cooling drag. In this form the external shape was identical with that of the faired body in the previous series of tests.

The air intake was faired over and the oil cooler louver (on the underside of the starboard wing) was locked in the closed position for these and all other tests without propeller.

2.3 Cooling fan

The cooling fan is of the high solidity type and is driven at propeller speed. Details are given in Appendix I and Fig.6 and a photograph of the rotor and stator is shown in Fig.7. The rotor and stator consist of rings carrying separate adjustable-pitch blades. The angles at which the blades were set were those found in previous tests of the fan[3] (in the R.A.E. full scale fan testing tunnel), to give the highest pressure rise. The rotor and stator rings are carried on dished plates bolted to the rear of the propeller hub and to the front of the crankcase respectively.

3 Range of investigation

3.1 Flow and total head measurements

3.11 Tests without propeller

The tests without propeller were made with the entry cowl shape as for the engine running tests without fan, but with the cut-outs in the spinner for the propeller blades and the gap between the spinner and fan ring sealed over with fabric.

Total heads and flows were determined over a range of gill positions. The presence of the exhaust pipes in the gill exit complicated the measurements there and made a complete traverse to obtain the flow impracticable. The following procedure was therefore adopted: the rear portions of the exhaust pipes were removed and the flows determined from entry and exit measurements. The tests were then repeated with the exhaust pipes replaced and, using the exit flow against entry flow curves from the tests without flow as a calibration, the new true exit flow was determined. A factor (true-exit flow)/(computed exit flow) was then determined, where the computed exit flow was that calculated from the exit pitot-static readings assuming the only effect of the exhaust pipes was to reduce the exit area. This factor which varied from 1.05 with the gills closed to 0.89 with the gills open, was then applied to all subsequent tests, since from previous investigations the factor was expected to remain constant at the same gill position.

The flow was computed as $\Sigma\, v\, \delta a$ at entry and $\Sigma\, v\, \delta a$ multiplied by the factor at exit, where

v = local velocity

δa = representative area served by pitot tube.

The total heads at entry and exit were computed as $\Sigma\, h\, v\, \delta a / \Sigma\, v\, \delta a$, and the total head at the cylinders as $\Sigma\, h\, \delta a / \Sigma\, \delta a$ as the velocity head there was only a small proportion of the total head; where h = local value of total head.

The pressure integrating ring readings were also taken.

The measurements were made at a windspeed of 160 ft./sec. with and without the rear portions of the exhaust pipes fitted, and scale effect tests were also made at 60 and 100 ft./sec. with the exhaust pipes removed. The above tests were made at a wing geometrical incidence of 1.5° and a few tests were also made at 13.4° at a tunnel speed of 100 ft./sec.

3.12 Engine running tests without fan

In order to obtain direct comparison with the previous series of tests the present series was made at the same engine speeds and wind speeds and with engine developing the same powers. The appropriate values of propeller pitch setting were determined from a calibration made on a 1500 H.P. electric motor.

The total head values and exit flow were calculated as for the 'no propeller' tests. Readings of the pressure integrating rings were again taken.

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The total head values and exit flow were calculated as for the 'no propeller' tests. Readings of the pressure integrating rings were again taken.

The test conditions in the tunnel are given in Table I below.

Table I

Tunnel Conditions

Equivalent flight conditions	J*	Tunnel speed (ft./sec.)	N+ (r.p.m.)	Propeller pitch setting (At 0.7 radius)	Wing incidence	Gill position	Approx. B.H.P.
Weak mixture cruise and all out level 'S' gear	2.2	170	907	52° 7'	1° 30'	Complete range	150
Climb 'S' gear	1.6	170	1240	44° 31'	1° 30'	Complete range	290
					6° 25'	½ open & open	
Climb 'M' gear	1.2	170	1655	37° 28'	1° 30'	Complete range	510

* These values of J differ slightly from those in the previous series of tests as the propeller diameter is different.

\+ N = crankshaft speed, propeller reduction gear = 0.4.

Some ground running tests were also made at 1890 and 2000 r.p.m. at a propeller pitch setting of 30° 42' and at 1890 r.p.m. at a pitch setting of 32° 37'. The free stream velocity was not zero owing to the tunnel velocity induced by the propeller.

3.13 Engine running tests with fan

No measurements were possible at the entry with the fan, rotor and stator in position, but measurements of total head at the front of the cylinders, total head and flow at the gill exit and pressure integrating ring readings were taken. Total heads and exit flows were computed in the same way as for tests without fan.

The test programme described in the previous paragraph (3.12) was repeated with the fan fitted.

3.2 Internal cooling drag with and without propeller

The total internal cooling drag has been calculated using the formula due to Betz. The drag is split into components* which show the relative loss in the wake to that across various parts of the engine. This method of analysis is the same as that used in the previous parts of this report and is fully described in Appendix III of Part I[1].

3.3 Measured drags

3.31 Complete rig (without propeller)

Lift and drag measurements were made over the whole range of gill openings, the installation being as described in para. 3.11 for the 'no propeller' tests with exhaust system complete.

* The drag component is defined as $\frac{\Delta h \times Q}{V}$ where Δh is the loss in mean total head across the part under consideration.

3.32 Faired body

Lift and drag measurements were made over a range of wing incidence from $-0.5°$ to $13.5°$ with the faired body on wing as described in para. 2.2.

3.33 Drag corrections for lift

In calculating the power plant drag the value of the faired body drag at the same value of C_L, as the tests with flow, has been used.

4 Results and Discussion

The results discussed below are presented in Table 5.

4.1 Entry loss

The total head loss before the cylinders can conveniently be divided into two parts; the loss into the cowl entry and the loss in the diffuser. The two planes of measurement are shown in Fig.3.

4.11 No propeller (Figs.8 and 9)

The total head loss up to the cowl entry is small (about 0.02q) at an entry v/V* of 0.8 but rises to 0.10q as the v/V is decreased to 0.55. The radial distribution (Fig.9) shows this to be due to a breakaway from the spinner. The total head at the front of the cylinders drops slightly from 0.79q with gills closed ($v/V = 0.55$) to 0.76q with gills open ($v/V = 0.78$). The diffuser loss obtained by subtraction varies from 0.11q to 0.22q as v/V increases from 0.55 to 0.80. The diffuser loss in terms of entry velocity head is discussed in para. 4.12 below.

4.12 Effect of propeller

The results in Fig.8b are for $J = 2.24$, corresponding to weak mixture cruise and all out level. The presence of the blade roots increases the loss into the cowl entry to 0.08q at $v/V = 0.8$, compared with 0.02q without propeller. and has very little effect at $v/V = 0.55$. Fig.10 shows that changing from level speed to climbing conditions increases the available total head by about 0.03q.

The diffuser loss decreases when the propeller is added by an amount which is almost independent of J (see Fig.10). This loss in terms of the entry velocity head $\frac{1}{2}\rho v^2$ is given in Table II below.

Table II

Diffuser loss in terms of entry velocity head

v/V	$P/\frac{1}{2}\rho v^2$			
	No propeller	$J = 2.24$	$J = 1.63$	$J = 1.22$
0.5	0.43	0.23	0.26	0.23
0.6	0.41	0.29	0.29	0.26
0.7	0.37	0.28	0.28	0.26

* v is used to represent the mean entry velocity i.e. Q/(Entry area, 2.51 sq.ft.).

The improvement with engine running is probably due to the swirl induced by the propeller as it is known that a moderate amount of swirl improves the efficiency of a diffuser.

The radial distribution of total head at the cowl entry (Fig.9) is fairly uniform with the gills open both for tests at J = 2.24 and those without propeller, but closing the gills produced a falling off of the total head near the crankcase fairing due to a breakaway from the spinner. At the front of the cylinders the radial distribution of total head is not uniform due to the bad diffuser shape. It has a peak value about on a level with the cylinder head when the fan is absent. Fitting the fan and liner causes this peak to move radially inwards slightly.

4.13 Ground running (i.e. tunnel fan idling)

The total head (in inches of water) just inside the cowl entry and at the front of the cylinders is shown in Fig.11, together with the free stream $\frac{1}{2}\rho V^2$ (due to the induced tunnel flow), for the tests at 1890 engine r.p.m. at a propeller pitch setting of 30° 42'. There is an increase of total head of one inch of water above the free stream dynamic head at the front of the cylinders with the gills open.

4.14 Comparison with previous tests

Table III below gives the values of total head just inside the cowl entry and at the front of the cylinders at two values of cooling flow for the three installations tested.

Table III

Installation		Buckingham Prototype (Part I) Fan off		Buckingham Production (Part II) No fan		Tempest type high speed entry. Fan off	
Entry area (sq.ft.)		3.81		3.98		2.51	
Condition	Flow	T.H./q Entry	T.H./q Cylinders	T.H./q Entry	T.H./q Cylinders	T.H./q Entry	T.H./q Cylinders
No propeller	140	0.95	0.75	0.93	0.81	0.91	0.79
	195	0.99	0.78	0.97	0.84	0.98	0.76
Weak mixture cruise and all out level	140	0.78	0.67	0.72	0.69	0.90	0.83
	195	0.78	0.64	0.73	0.70	0.92	0.76

With the propeller off the entry total head shows little variation at the higher flow but at the lower value the high speed entry is about 0.03q worse than the other two, due to the larger percentage area affected by the breakaway from the spinner. The high diffuser loss with the Tempest type entry causes a slightly lower value (about 0.05q) of total head at the front of the cylinders than with the previous installation (Production Buckingham).

Under engine running conditions corresponding to weak mixture cruise and all out level the total head at entry shows a marked improvement (about 0.15q) over the previous installations. This gain can be attributed to two causes:-

(a) the improved blade root design, and

(b) the more favourable pressure gradient in which the blade roots are working, resulting from the higher entry v/V.

The improvement in total head at the cylinders is not so great as that at entry due to the higher diffuser loss and amounts to about 0.10q.

This comparison shows the necessity of making tests with the propeller running, and the advisability of doing so under full scale conditions owing to the known scale effect on propeller blade roots.

4.15 Effect of cooling fan

The effect of the fan on the total head at the front of the cylinders is shown in Figs.12a, 12b and 12c. The total head, in inches of water at 2400 engine r.p.m. (ground level), is plotted against forward speed in knots. The fan produces an increase of total head of 3 to 4 inches of water at low forward speeds rising to 5 inches at a flight speed of 100 knots. With the gills closed this increase is maintained up to the highest speed represented (270 knots), but with the gills half open the pressure increase falls to only 1½ inches at 270 knots. With the gills fully open the pressure increase has fallen to zero at about 265 knots.

4.2 Static pressure at the gill exit

The mean static pressure at the gill exit is shown in Fig.13 plotted against gill position or exit area. The curves obtained for 'no propeller' and J = 2.24 are nearly parallel, the latter being about 0.03q below. The mean static pressure for the 'no propeller' tests falls from -0.01q with the gills closed to -0.26q with the gills open.

The circumferential variation of static pressure has not been affected by the change in nose cowl shape and is as described in Part II. The variation for a given gill position is about 0.3q with a minimum at the bottom of the engine and maxima just ahead of the wings.

4.3 Cooling flow

As no measurements could be made in the cowl entry with the cooling fan fitted, the cooling flow calculated from measurements at the gill exit has been used throughout the report for the sake of consistency. The term cooling flow is therefore used to denote that calculated from exit measurements unless the entry is specifically mentioned. All flows quoted have been corrected to free stream temperature.

4.31 Variation of cooling flow with exit area

The cooling flow is plotted against gill exit area in Fig.14 for no propeller, and for the cruise and all out level conditions without fan. The range is from about 135 cu.ft./sec. at 100 ft./sec. with the gills closed to 195 with the gills open.

The cooling flow calculated from entry measurements is also plotted for comparison with those obtained from exit measurements. The agreement between the two sets of values is good and the slightly lower exit values could be due to cowl leaks.

4.32 Effect of fan

The cooling flow expressed in cu.ft./sec. at 2400 engine r.p.m. is shown in Fig.15 plotted against flight speed with and without fan.

For ground running and low forward speeds the fan produces an increase of flow with the gills open of about 45%. As the flight speed increases this drops to 25% at 100 knots, 10% at 200 knots and at the highest speed represented (270 knots) the increase is only 6%. With the gills closed the percentage increase is rather higher - about 1.2 of that with the gills open.

4.33 Effect of incidence

The effect on the cooling flow of increasing the incidence by 5° at $J = 1.63$ is to decrease the flow by about 1% with the gills open and 2% with the gills closed. An increase of 12° with no propeller produces a decrease in flow of only 2% with the gills open.

4.4 Baffle constants

The baffle constants K_1 and K_2 given in Table V are defined as:

$$K_1 = \frac{\Delta P_1}{\sigma (Q/100)^2}$$

$$K_2 = \frac{\Delta P_2}{\sigma (Q/100)^2}$$

where ΔP_1 = pressure integrating ring drop (inches of water).

ΔP_2 = total head drop from front of cylinders to gill exit (inches of water).

σ = free stream relative density.

Q = cooling air flow (cu.ft./sec.).

As in Parts I and II K_1 is quoted for comparison with flight tests. The baffle system and gill exit have not been altered since the tests discussed in Part II. The values of K_2 obtained are plotted in Figs. 16 and 17.

4.41 No propeller

Tests were made over a range of gill openings at wind speeds of 60, 100 and 160 ft./sec. with the rear portions of the exhaust pipes removed. The effect of increasing the wind speed at constant gill position is to reduce the baffle constant slightly; the baffle constant appears to vary as $(\text{Reynolds No.})^{-0.10}$ as was found on the previous series of tests. Closing the gills produces an increase in baffle constant of about 0.12 at 60 ft./sec. falling to 0.05 at 160 ft./sec. The mean value at 160 ft./sec. is about 0.53, with and without the exhaust pipes fitted.

4.42 Tests at correct J for flight

The decreased accuracy in cooling flow measurement with the engine running makes it impossible to separate out the effects of Reynolds number, swirl, temperature etc. In general the baffle constant falls from about 0.62 with the gills closed to 0.56 with the gills open, without the fan. With the fan fitted the baffle constant is nearly constant at a value of 0.52. The stator ring permits very little variation of swirl or total head distribution at the front of the cylinders with change of J or gill position, which probably accounts for the more constant values.

4.43 Ground running

Without fan the values of K_2 are about 0.8 to 0.9 while with the fan fitted they are nearly constant at 0.60. The high values without fan are probably due in part to the large swirls (up to 50° at the cowl entry) while the increased temperature rises of the cooling air would be expected to produce a higher value of baffle constant than for the tests at values of J corresponding to flight conditions.

4.44 Comparison with previous tests

For tests at values of J corresponding to flight conditions the mean values of K_2, i.e. 0.59 without fan and 0.52 with fan, are in fairly good agreement with the mean value of 0.50 obtained in Part II. The change of baffle constant with gill position is less marked in the present series, due* possibly to the different flow pattern at the front of the cylinders.

4.5 Drag

4.51 Drag measurements without propeller

The measured cooling drag and calculated internal drag are shown in Fig.18 and the drag analysis using the same nomenclature as in Part I is given in Table IV below at a C_L of 0.06.

Table IV

Drag analysis at 100 ft./sec. (no propeller)

Gill position	Closed	½ open	Open
Gill exit area (sq.ft.)	2.19	4.22	5.99
Cooling flow (cu.ft./sec.)	136	179	197
Minimum internal drag (lb.)	7.7	21.1	32.9
Residual internal drag (lb.)	4.9	11.2	17.3
External cooling drag (lb.)	-2.2	3.9	9.4
Faired body drag+ (lb.)	17.2	17.2	17.2
Power plant drag∅ (lb.)	27.8	53.4	76.8

\+ The faired body drag quoted is that obtained in Part I as the shapes are identical.

∅ The power plant drag quoted does not include the drag of the oil cooler or air intake.

4.52 Internal drag analysis

The drag components are plotted against cooling air flow in Fig.19a for weak mixture cruise and all out level conditions and in Fig.19b for 'no propeller' tests.

* The technique of flow and total head measurements has been improved since the last tests and this is described in Appendix II.

4.53 Effect of fan

If the engine is supplying a constant B.H.P. the power absorbed by the fan is obtained at the cost of a loss in the power supplied to the propeller. The resultant loss in propeller thrust can be considered as an addition to be made to the total internal drag as given by the Betz formula when a fan is fitted. This loss in propeller thrust has been calculated using the values of power required for the fan as obtained in the full scale fan testing tunnel[3] and assuming a propeller efficiency of 85%; and is quoted in Table V.

The sum of the total internal drag and the equivalent drag due to the power absorbed by the fan is plotted in Fig. 20a for weak mixture cruise and all out level conditions and in Fig. 20b for climb tests at J = 1.22. In general for a given cooling flow, there is a reduction of drag due to fitting the fan except at the lowest values of exit area. Assuming the external drag to be dependent only on the exit flap position, there is a reduction of power plant drag, at a given value of cooling flow, at all gill settings.

4.6 Fan characteristics

The pressure rise of a fan is presented in the form of a graphical relation between the static pressure rise coefficient K_S and the flow coefficient Λ defined as

$$K_S = \frac{\Delta S}{\frac{1}{2}\rho(\pi n d)^2} \quad \text{and} \quad \Lambda = \frac{Q}{\pi n d A}$$

where ΔS = static pressure rise across the fan (lb./sq.ft.).

ρ = density of the cooling air (slugs/cu.ft.).

n = speed of rotation of the fan (r.p.s.).

d = mean diameter of the fan (ft.).

Q = volume flow of cooling air (cu.ft./sec.).

A = annular area in the plane of the fan (sq.ft.).

Assuming the total head loss into the entry and in the diffuser to be unaffected by the presence of the fan at the same value of cooling flow, the increase in pressure at the front of the cylinders should be equal to the static pressure rise across the fan. Two pressure rise coefficients $K_{S_{CYL}}$ and K_{S_R} have therefore been calculated as

$$K_{S_{CYL}} = \frac{\Delta S_{CYL}}{\frac{1}{2}\rho(\pi n d)^2} \quad \text{and} \quad K_{S_R} = \frac{\Delta S_R}{\frac{1}{2}\rho(\pi n d)^2}$$

where ΔS_{CYL} = increase in the mean total head at the front of the cylinders, at the same cooling flow, due to fitting the fan (lb./sq.ft.).

ΔS_R = increase in the front pressure integrating ring reading, at the same cooling flow, due to fitting the fan (lb./sq.ft.).

The values of $K_{S_{CYL}}$ and K_{S_R} calculated from the engine running tests are shown in Fig. 21 plotted against Λ, together with the values of

K_S obtained in the full scale fan testing tunnel[3]. The values obtained from the tests corresponding to climb conditions (J = 1.22 and 1.63) are in good agreement with the fan tunnel results. The values obtained from the tests corresponding to weak mixture cruise and all out level conditions (J = 2.24) appear to be much higher than the fan tunnel results, but actually the difference is only 0.03q for $K_{S_{CYL}}$ and 0.05q for K_{S_R} at this value of J. The values of K_{S_R} are about 0.02q greater than $K_{S_{CYL}}$ for all flight conditions.

No comparison is possible for the values obtained from the ground running tests as no fan tunnel results are available at such a low value of Λ.

The effect of an increase of wing incidence of 5° at a J of 1.63 is to reduce the values of $K_{S_{CYL}}$ and K_{S_R} by about 0.05 which is equivalent to 0.01q at this value of J.

5 Conclusions

5.1 Entry loss

The entry loss up to the cylinders with no propeller is 0.22q (compared with 0.23q with the C.T.A. system and 0.17q with the previous low speed entry) mainly due to a diffuser loss of 0.18q.

The propeller reduces the loss up to the cylinders to 0.19q for all flight conditions (compared with 0.34q for the C.T.A. system and 0.31q for the previous low speed entry).

Under ground running conditions the increase in total head at the cylinders due to the propeller is 1.3 inches of water at 2000 r.p.m. (compared with 0.5 inches with the C.T.A. system and 1.0 inches with the previous low speed entry). Addition of the fan increases this to about 3.8 inches of water.

At 2400 r.p.m., for flight speeds above 100 knots, the fan increases the total head at the cylinders by about 5 inches of water at ground level with the gills closed. With the gills open this increase falls from 5 inches at 100 knots to zero at 265 knots.

5.2 Cooling flow

Without fan the cooling flow can be varied from 135 to 195 cu.ft./sec. at 100 ft./sec. by altering the gill position. At a given gill position the fan increases the flow by about 50% at ground running and low forward speeds. This increase has fallen to 30% at a J of 1.0 and 10% at a J of 2.0.

5.3 Baffle constant

The baffle constant at values of J corresponding to flight conditions is fairly constant at 0.52 with the cooling fan fitted and 0.59 without.

5.4 Drag

The total power plant drag, excluding the drag of the oil cooler, with no propeller is 28 lb. at 100 ft./sec. at C_L = 0.06 with the gills closed and 77 lb. with the gills fully open (compared with 34 lb. and 72 lb. with the C.T.A. system, and 30 lb. and 77 lb. with the previous low speed entry).

The faired body drag has been taken as 17.2 lb. as previously measured on the C.T.A. installation.

5.5 General effect of fan

For a given cooling flow the addition of the fan decreases the net internal drag in nearly all cases. If the external drag is taken as a function of gill position only, then the net propulsive efficiency of the engine propeller unit is increased in all cases by the addition of the cooling fan. Under cruise conditions this increase is about 4 lb. at 100 ft./sec. with the gills half open and 10 lb. with the gills fully open. Since the aircraft drag is of the order of 100 lb. per engine the saving when trying to satisfy tropical conditions is considerable.

5.6 Fan characteristics

The agreement between the results from the engine running tests and those from the full scale fan testing tunnel is fairly good, the measured increase in total head at the front of the cylinders being within 0.02q of that calculated from the fan tunnel values of K_S. No loss in fan performance due to the presence of the propeller blade roots is apparent. An increase in incidence of the installation of 5° at $J = 1.63$ reduced the measured total head increase at the front of the cylinders due to the fan by very little (0.01q).

List of Symbols

A = annular entry area in plane of fan (2.51 sq.ft.).

δa = representative area served by pitot-static tube (sq.ft.).

B.H.P. = horsepower absorbed by propeller and cooling fan. (The propellor horsepower is obtained from a calibration on a 1500 H.P. electric motor.)

C.T.A. = circular taper assembly front exhaust ring system. A full description is given in Part I[1].

D = propeller diameter (12.75 ft.).

d = mean diameter of cooling fan (3.05 ft.).

h = local total head.

J = propeller advance diameter ratio $= \dfrac{V}{nD}$.

Λ = fan flow coefficient $= \dfrac{Q}{\pi\, n\, d.A}$.

K_S = fan static pressure rise coefficient $= \dfrac{\Delta S}{\frac{1}{2}\rho(\pi\, n\, d)^2}$.

K_{S_R} = fan pressure rise coefficient defined as $\dfrac{\Delta S_R}{\frac{1}{2}\rho(\pi\, n\, d)^2}$

$K_{S_{CYL}}$ = fan pressure rise coefficient defined as $\dfrac{\Delta S_{CYL}}{\frac{1}{2}\rho(\pi\, n\, d)^2}$

K_1 = baffle constant based on pressure integrating ring drop $= \dfrac{\Delta P_1}{\sigma\left(\frac{Q}{100}\right)^2}$.

K_2 = baffle constant based on total head drop from front of cylinders to gill exit = $\dfrac{\Delta P_2}{\sigma\left(\frac{Q}{100}\right)^2}$.

N = engine crankshaft r.p.m.

n = propeller (and fan) r.p.s. (reduction gear 0.4).

ΔP_1 = pressure integrating ring drop (inches of water).

ΔP_2 = total head drop from front of cylinders to gill exit (inches of water).

Q = cooling air flow (cu.ft./sec.).

Q_{100} = cooling air flow (cu.ft./sec.) at 100 ft./sec.

q = free stream dynamic head = $\frac{1}{2}\rho V^2$.

R = propeller radius (6.375 ft.).

ΔS = static pressure rise across fan (lb./sq.ft.).

ΔS_R = increase in front pressure integrating ring reading (lb./sq.ft.), due to fitting cooling fan (at the same values of Q and n).

ΔS_{CYL} = increase of total head at the front of the cylinders (lb./sq.ft.) due to fitting cooling fan (at the same values of Q and n).

ρ = free stream density (slugs/cu.ft.).

σ = free stream relative density.

v (para.3.11) = local velocity (ft./sec.).

v (paras.4.11 and 4.12) = mean cowl entry velocity = Q/A (ft./sec.).
V = free stream velocity (ft./sec.).

References

No.	Author	Title, etc.
1	C.Roe	Drag and cooling tests inthe 24 ft. tunnel on a Centaurus-Buckingham wing nacelle installation. Part I - tests with C.T.A. exhaust system. Report No. Aero.1976, October, 1944.
2	Shaw and Owen	Drag and cooling tests in the 24 ft. tunnel on a Centaurus-Buckingham wing nacelle installation. Part II - tests with rear swept exhaust system. Report No. Aero.2063, July, 1945.
3	Fail	Tests of a high solidity engine cooling fan in the R.A.E. full scale fan testing tunnel. Report No. Aero.2068, July, 1945.

TABLE 5.

FLIGHT CONDITION	GROUND RUNNING										
J	0.00										
WING INCIDENCE	1°30'										
PROPELLER BLADE ANGLE (AT 0.7R)	39°48'										32°2'
ENGINE CRANKSHAFT R.P.M.	1800						2000				1800
NOMINAL WINDSPEED (FT/SEC)	0						0				0
GILL POSITION	CLOSED		½ OPEN		OPEN		CLOSED	½ OPEN		OPEN	OPEN
FAN	OFF	ON	OFF	ON	OFF	ON	ON	OFF	ON	OFF	OFF
TRUE VELOCITY (FT/SEC)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
½ρV² (INS. OF WATER)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	PRESSURES ARE IN INCHES OF WATER										
TOTAL HEAD IN COWL ENTRY	[illegible]		[illegible]		[illegible]			[illegible]		[illegible]	[illegible]
TOTAL HEAD AT FRONT OF CYLINDERS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FRONT PRESSURE INTEGRATING RING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
REAR PRESSURE INTEGRATING RING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL HEAD AT GILL EXIT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PRESSURE INTEGRATING RING DROP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	COOLING FLOW IS ACTUAL FLOW AT ABOVE VELOCITY (CU.FT/SEC)										
COOLING AIR FLOW [illegible]	124	168	176	258	186	273	168	168	268	181	194
BAFFLE CONSTANT [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BAFFLE CONSTANT [illegible] (K)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FLIGHT CONDITION	CLIMB																
J	1.20						1.43										
WING INCIDENCE	1°30'						1°30'						6°25'				
PROPELLER BLADE ANGLE (AT 0.7R)	37°28'						46°31'						44°31'				
ENGINE CRANKSHAFT R.P.M.	1885						1840						1840				
NOMINAL WINDSPEED (FT/SEC)	170						170						170				
GILL POSITION	CLOSED		½ OPEN		OPEN		CLOSED		½ OPEN		OPEN		CLOSED	½ OPEN		OPEN	
FAN	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	ON	OFF	ON	OFF	ON
	PRESSURES ARE IN TERMS OF ½ρV²																
	COOLING FLOW IS EXPRESSED IN CU.FT/SEC AT 100 FT/SEC																
COOLING AIR FLOW	129	181	176	214	186	230	131	152	175	187	197	210	146	170	196	198	218
	INTERNAL DRAG AND DRAG COMPONENTS IN LB AT 100 FT/SEC																

FLIGHT CONDITION	WEAK MIXTURE CRUISE AND ALL OUT LEVEL							
J	2.84							
WING INCIDENCE	1°30'							
PROPELLER BLADE ANGLE (AT 0.7R)	52°7'							
ENGINE CRANKSHAFT R.P.M.	1807							
NOMINAL WINDSPEED (FT/SEC)	170							
GILL POSITION	CLOSED		½ OPEN		½ OPEN		OPEN	
FAN	OFF	ON	OFF	ON	OFF	ON	OFF	ON
	PRESSURES ARE IN TERMS OF ½ρV²							
	COOLING FLOW IS EXPRESSED IN CU.FT/SEC AT 100 FT/SEC							
COOLING AIR FLOW	130	145	159	170	173	185	191	203
	INTERNAL DRAG AND DRAG COMPONENTS IN LB AT 84 FT/SEC							

FLIGHT CONDITION	NO PROPELLER (EXHAUST PIPES FITTED)				
WING INCIDENCE	1°30'				
NOMINAL WINDSPEED (FT/SEC)	160				
GILL POSITION	CLOSED	½ OPEN	OPEN	½ OPEN	OPEN
FAN	OFF				
	PRESSURES ARE IN TERMS OF ½ρV²				
	COOLING FLOW IS EXPRESSED IN CU.FT/SEC AT 84 FT/SEC				
COOLING AIR FLOW	136	163	178	187	187
	INTERNAL DRAG AND DRAG COMPONENTS IN LB AT 84 FT/SEC				

FLIGHT CONDITION	NO PROPELLER (EXHAUST PIPES REMOVED)										
WING INCIDENCE	1°30'									13°18'	
NOMINAL WINDSPEED (FT/SEC)	60		100		160					100	
FAN	OFF										
	PRESSURES ARE IN TERMS OF ½ρV²										
	COOLING FLOW IS EXPRESSED IN CU.FT/SEC AT 100 FT/SEC										
COOLING AIR FLOW	128	183	132	168	134	166	188	191	202	176	194
	INTERNAL DRAG AND DRAG COMPONENTS IN LB AT 100 FT/SEC										

Row labels of the drag section: LOSS UP TO CYLINDERS — ENTRY, DIFFUSER; ENGINE + DUCT; WAKE; TOTAL INTERNAL (DETD); [illegible]; TOTAL INTERNAL + LOSS IN PROPELLER WAKE.

MAIN TABLE OF RESULTS.

Attached:

Drgs. 19073S - 19087S
Negs. 70465, 70466, 70467, 70468.
Appendices I and II

Circulation:

C.S.(A)	
D.G.S.R.(A)	
D.S.R.(A)	
A.D.A.R.D.(Res)	(Action copy)
A.D.S.R. (Records)	
D.A.R.D.	
P/D.T.D. (Air)	
R.T.P./T.I.B.	(110 + 1)
D.D.A.R.D. (Serv.)	
D.D.A.R.D. (Civ.)	
D.D.R.D. (Perf.)	
A.D.R.D.N.	
A.& A.E.E.	(2)
A.R.C.	(40)
Bristol Aeroplane Co. (Engines) per R.T.O.	(2)
D.Eng.R.D.	
A.D./R.D.E.3.	
A.D./R.D.E.4.	
A.D.(I).R.D.I.	(2)

Appendix I

Particulars of test installation

1 Centaurus Engine

Mark IV		
Double row radial, sleeve valve		
Diameter over cylinders		55.3 ins.
* Supercharger gear ratios		'M' 6.76 to 1, 'S' 9.03 to 1
Cylinders	Number	18
	Type	Air cooled
	Bore	5.75 ins.
	Stroke	7.0 ins.
	Compression ratio	7.2 to 1
	Barrels	No. F.B.102760 with 0.14 ins. pitch barrel finning
	Junkheads	Two piece No. F.B.93598
	Baffles	Cylinder head No. F.B.122968 Barrels Nos.121166 and 121167
Propeller rotation		Left hand tractor
Reduction gear ratio		0.4 to 1
Carburettor:		Claudel Hobson 160M

(R.A.E. injection carburettor is standard in service).

* Locked in 'M' gear for tunnel tests.

2 Propeller

Type	Rotol hydraulic ø with specially thin blade root sections.
Number of blades	4
Material	wood
Diameter	12 ft. 9 ins.
Blade section	Clark 'Y'
t/c ratio	10.2% at 0.7R
Solidity	0.14 at 0.7R
Blade drawing number	R.A.10093

ø Pitch locked for tunnel tests.

3 High solidity cooling fan

Material Laminated wood.

	Rotol Drawing No.	Nominal Blade length (ins.)	Tip Clearance (ins.)	Dia. (ins.)	Camber (degrees)	Blade Angles (degrees)	Chord (ins.)	Solidity
Rotor (51 blades)	R.A.16304	3.05	0.28	34.4 37.0 39.6	60 50 40	85 80.3 77	3.25 3.00 2.75	1.53 1.32 1.13
Stator (53 blades)	R.A.16305	3.30	0.07	34.4 37.0 39.6	55 55 55	70 70 70	3.00 3.00 3.00	1.47 1.37 1.28

Distance along camber line from L.E.	Distance between camber line and surface
	1.65%*
1.25%	2.27
2.5	3.08
5.0	3.62
7.5	4.02
10.0	4.55
15.0	4.83
20.0	5.00
30.0	4.89
40.0	4.57
50.0	4.05
60.0	3.37
70.0	2.62
80.0	1.86
90.0	1.49
95.0	
L.E. Radius	1.2%*
T.E. Radius	1.2%*
Camber lines are circular arcs of angles given above	
* % of chord	

4. <u>Wing-nacelle unit</u>

Wing.	Planform:	Rectangular
	Span:	20 ft.
	Chord:	11 ft. 9¾ ins.
	Maximum thickness:	17.6% (constant section)
	Camber:	2%
Nacelle.	Type:	Underslung
	Maximum cross-sectional area:	21 sq.ft.
	Engine thrust line:	Parallel to and 1 ft. 4½ ins. below wing chord line.
Cowl entry.	Type:	High entry velocity
	Spinner, fan and crankcase fairing diameter:	33.50 ins.
	Inner cowl diameter:	40.38 ins.
	Entry area:	2.51 sq.ft.
Exit.	Type:	Full circumference variable gill
	Distance forward from wing leading edge:	1 ft. 10 in.

/Table

Gill Position	Mean gap (ins.)	Gross exit area (sq.ft.)	*Nett exit area (sq.ft.)	Gill angle
Closed	2.00	2.56	2.19	0°
¼ open	2.75	3.56	3.19	6.5°
½ open	3.50	4.59	4.22	13°
¾ open	4.00	5.29	4.92	18°
Fully open	4.75	6.36	5.99	25.5°

* Nett exit area = gross exit area - exhaust pipe area (0.37 sq.ft.).

Air intake. Installed in wing leading edge on port side of nacelle (See Fig.2).

Oil cooler: Installed in wing leading edge on starboard side of nacelle (See Fig.2). Air flow controlled by louver on underside of wing.

Appendix II

Instrumentation for flow and pressure measurements

Since the earlier series of tests the instrumentation has been greatly improved and the following description should be read with reference to Figs.3, 4 and 22.

Cowl Entry

No measurements were possible in the entry with the fan fitted and the following refers to tests without fan.

Hitherto though measurements of total head in the cowl entry has been satisfactory, no attempt has been made to determine the cooling flow accurately. The high speed entry was expected to improve the flow pattern at the entry and surface statics (Fig.22a) were designed to replace the normal statics. Six of these were fitted flush into the nose cowl and six into the fan ring.

Six non-directional pitots (Fig.22d) were equally spaced round the entry in the same plane as the statics. These pitots had hollow stems, the rubber connections being inside the crankcase fairing. The stems were notched in 4 positions and each pitot could be set in any one of these positions by a screw in the guide block. A small hole was drilled in the front of the fan ring opposite each pitot to permit the insertion of a screwdriver.

A pair of swirl vanes was designed to obtain an approximate value of the angle of swirl. The vanes, spanning the gap, were of wood shaped to a thin symmetrical aerofoil section and had a spindle attached to the leading edge. The spindles passed through into the nose cowl and were pivoted in ball races. The vanes were statically balanced, the counterbalance weights being inside the nose cowl. The outer ends of the spindles carried light pointers to indicate to the positions of the vanes. The pointers with their scales could be viewed through perspex panels in the nose cowl.

The vanes were fitted on a horizontal diameter - one on the port side and one on the starboard - to determine the effect of incidence on the flow direction as well as the mean swirl angle. The pointer of the starboard vane can be distinguished in Fig.1.

Pitots at the front of the cylinders

The pitots at the front of the cylinders were inaccessible, even with the fan not fitted, because of the samll entry gap and a method had to be devised whereby the pitots could be set to predetermined positions without removing the wrapper cowling.

The instruments used are shown in Fig.22c. Each consisted of two non-directional pitots mounted a fixed distance apart on a thin rod and able to slide radially on two parallel guides. The rod was notched in four places and could be locked in any of these four positions by means of a split pin in a small block on the outside of the cowl.

Traverses were made at 6 circumferential positions. The arrangement of nose cowl stays and supports prevented the instruments being uniformly spaced circumferentially and the positions used were:-

in front of the centre lines of the rear bank cylinders 5, 9, 13 and 17.

and in front of the centre lines of the front bank cylinders 4 and 8.

Gill exit

The usual masts[1,2] were fitted at the gill exit, but the 12 pitot-static tubes were of the concentric type (Fig.22b). These were set on the site to lie in the direction of flow after this had been revealed by a preliminary wool tuft exploration.

Surface statics of a similar type to those fitted at the cowl entry were installed in the shoulder cowl and single tubes were fitted in the gill plates. The plane of traverse was taken ½ inch in from the exit (instead of at the exit as in previous tests) to line up with the surface statics.

Pressure integrating rings

The two pressure integrating rings were used as in the previous tests[1,2]. Each ring was a continuous tube, extending round the engine at about the same radius as the junkhead and having 3/32 inch holes through it at frequent intervals. The manometer connection was by a single tapping piece.

Junkhead static tubes

The junkhead static tubes[2] on cylinders 4, 5, 8 and 15 were still fitted but their inaccessibility made cleaning and maintenance very difficult and when several were found to be out of order no further readings were taken.

FIG. 1.

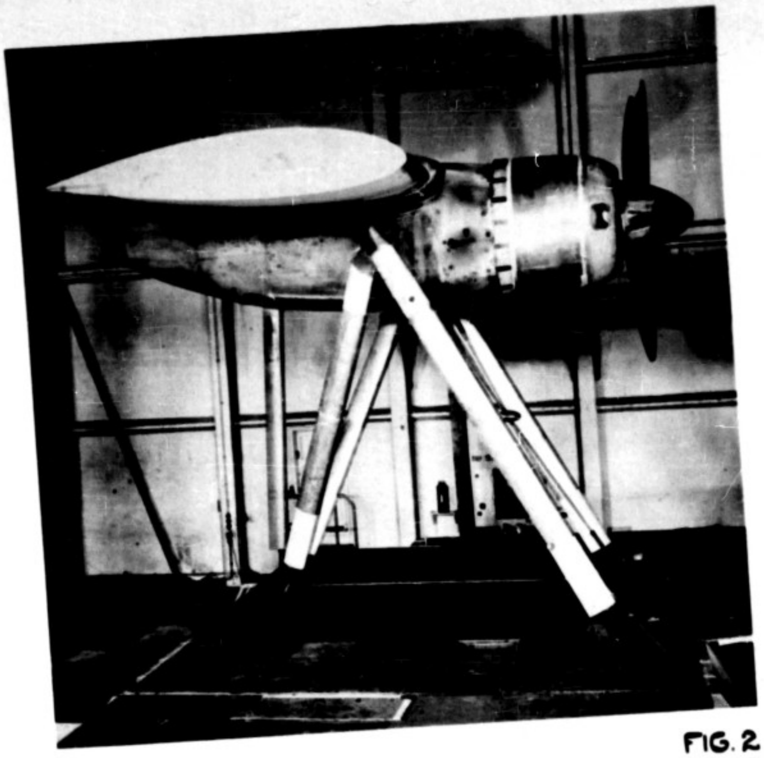
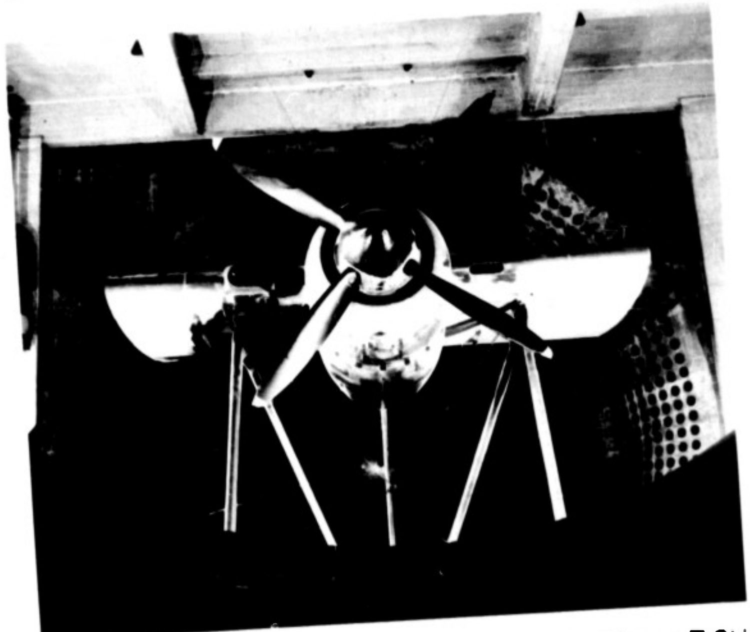
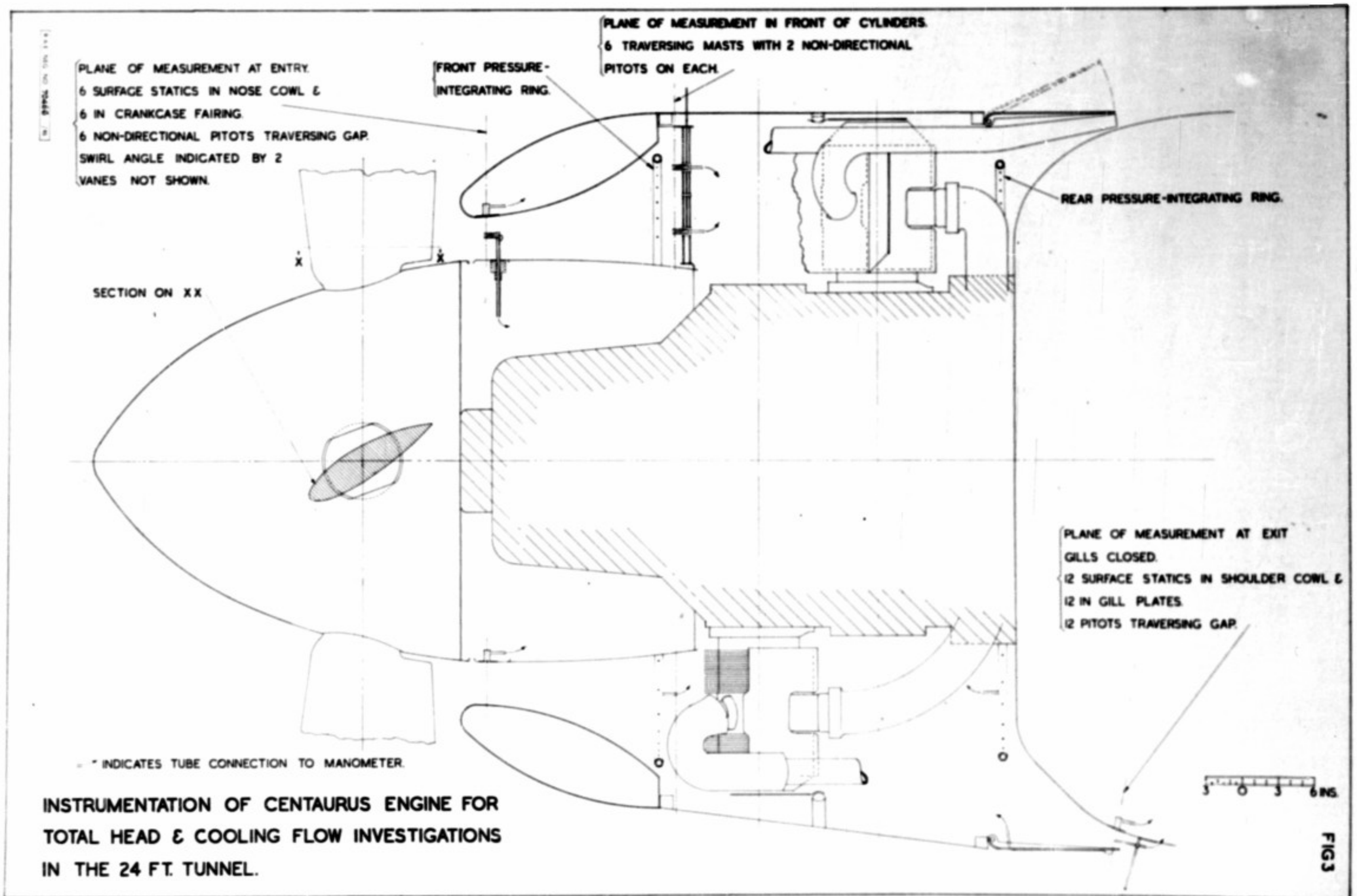


FIG. 2



CENTAURUS BUCKINGHAM NACELLE INSTALLATION
WITH HIGH ENTRY VELOCITY COWL.
COOLING FAN NOT FITTED

R.A.E. NEG NO 70465 /46



INSTRUMENTATION OF CENTAURUS ENGINE FOR TOTAL HEAD & COOLING FLOW INVESTIGATIONS IN THE 24 FT. TUNNEL.

FIG 3

No. 13029-5

REPORT AERO 2142
FIGS. 4a & 4b

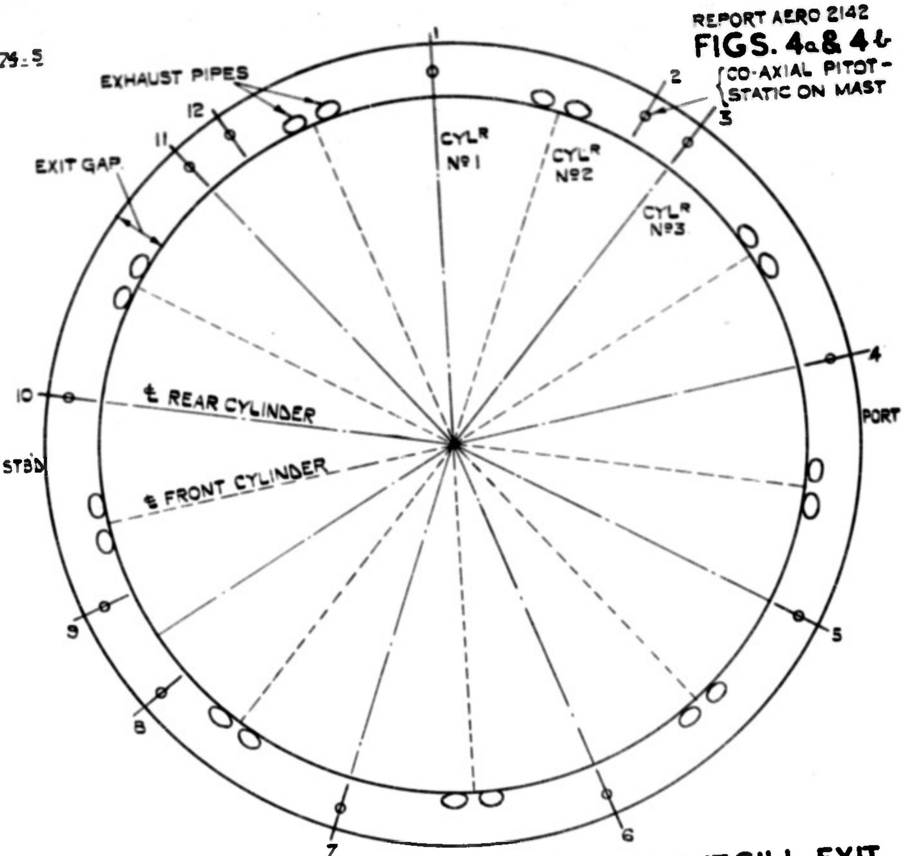


FIG. 4a. POSITION OF PITOT STATIC MASTS AT GILL EXIT

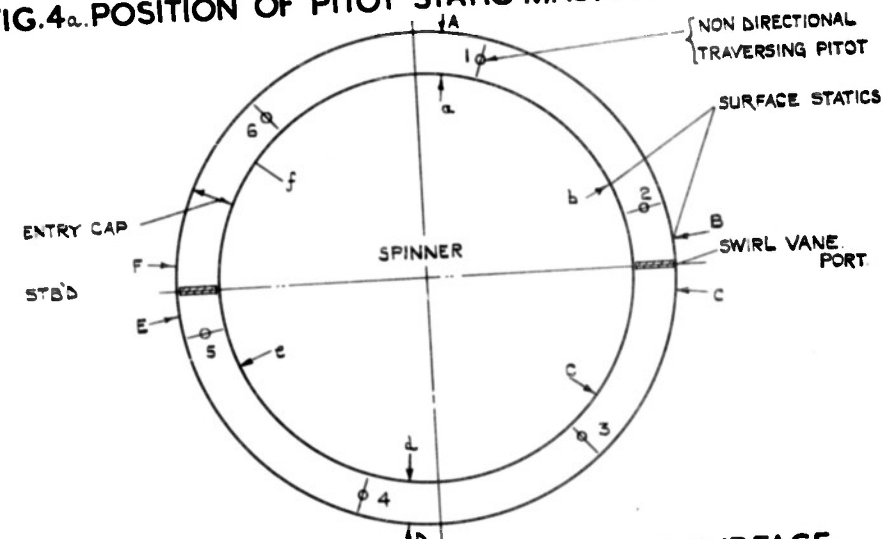


FIG. 4b POSITION OF TRAVERSING PITOTS & SURFACE STATICS AT ENTRY ——— FAN OFF

24

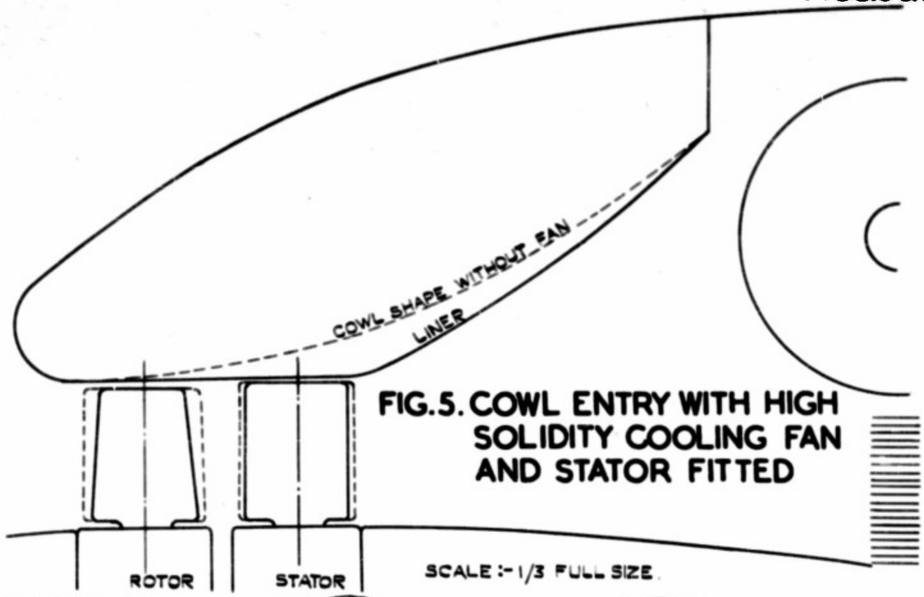


FIG.5. COWL ENTRY WITH HIGH SOLIDITY COOLING FAN AND STATOR FITTED

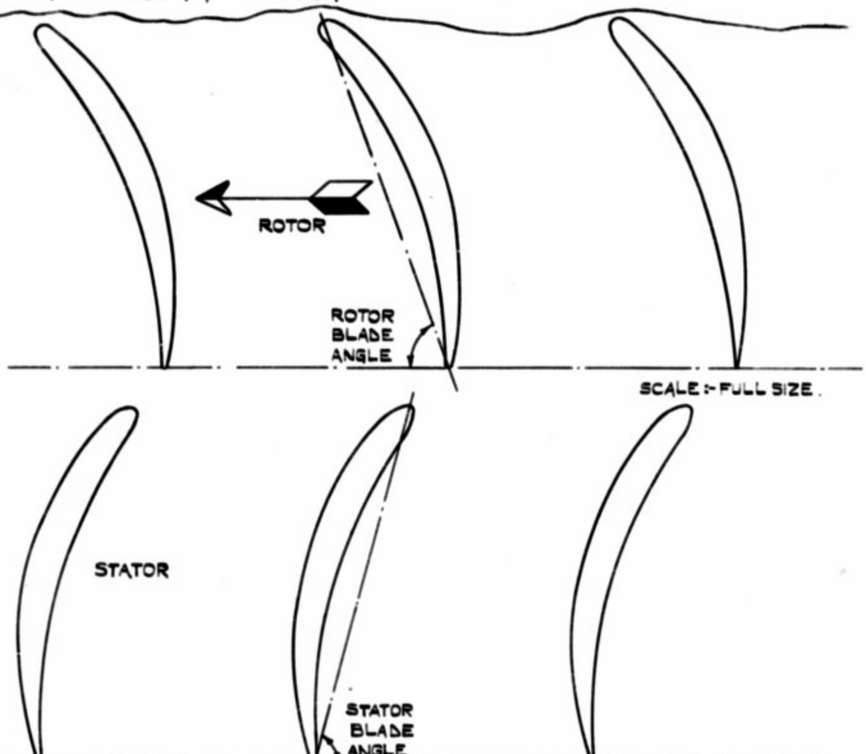
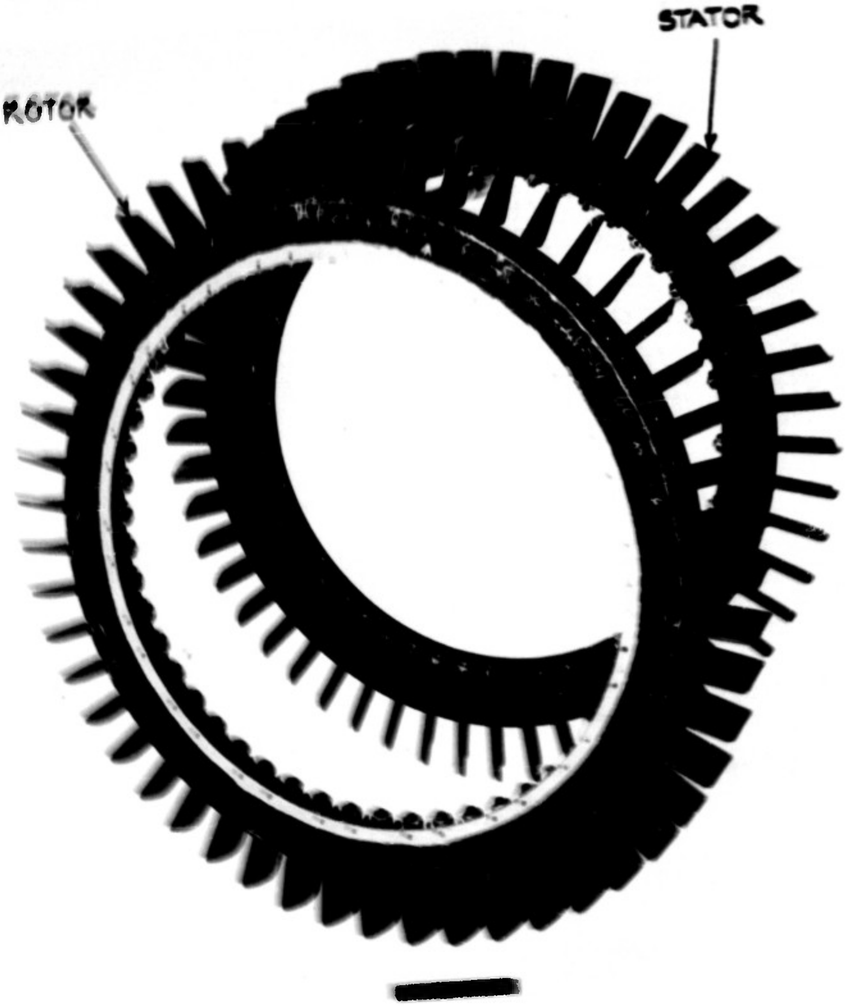


FIG.6. HIGH SOLIDITY COOLING FAN SKETCH OF BLADING

FIG. 7.



HIGH SOLIDITY COOLING FAN.

(NOTE: AXIAL CLEARANCE OF ROTOR AND STATOR HAS BEEN INCREASED FOR CLARITY.)

NEG. NO. 75857

No. 19076.S.

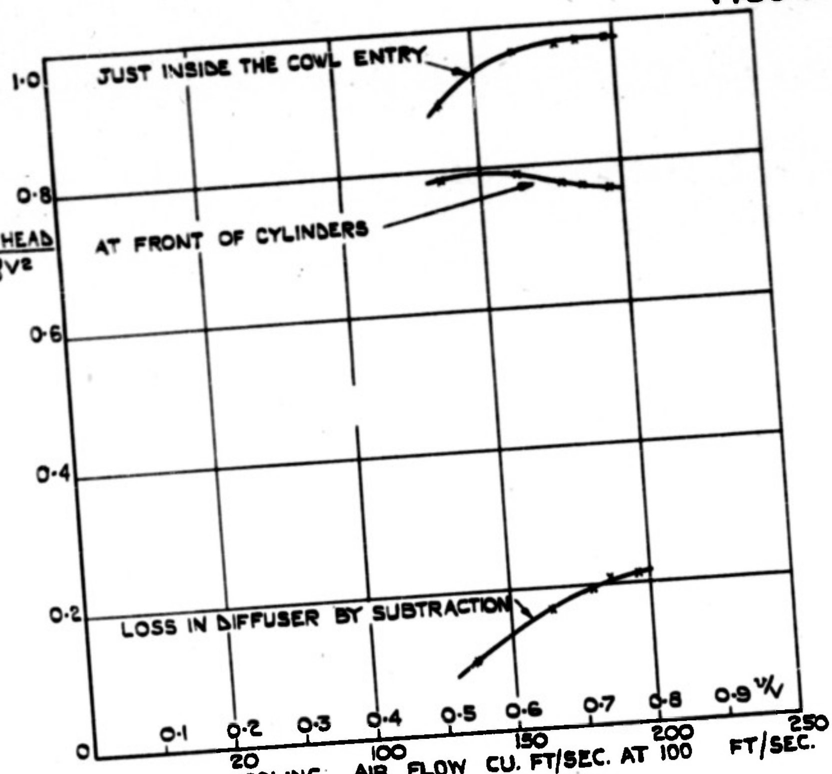


FIG. 8a NO PROPELLER.

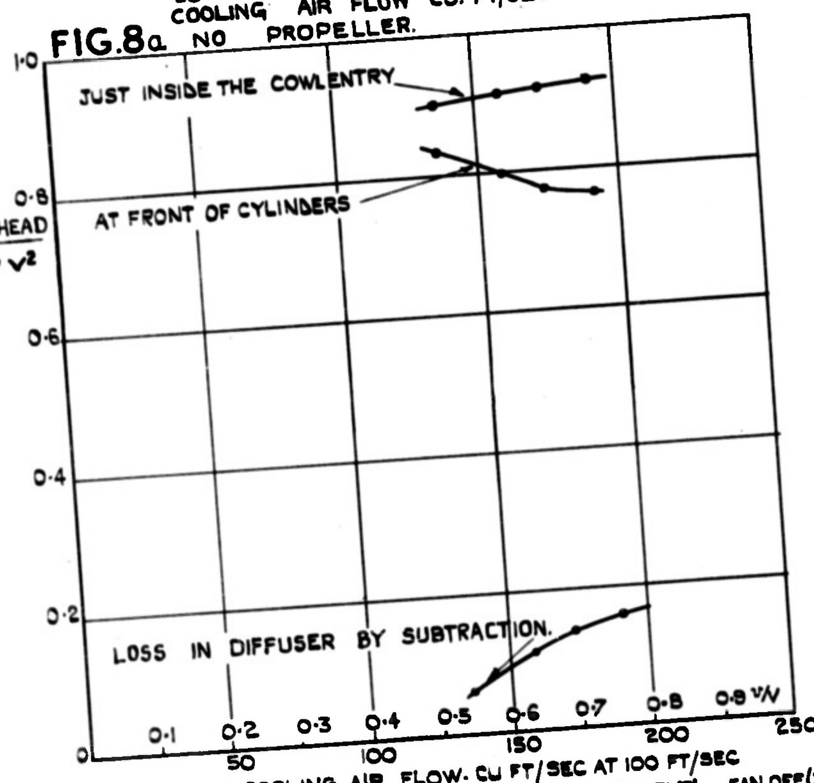


FIG 8b WEAK MIXTURE CRUISE AND ALL OUT LEVEL FAN OFF (J=2·24)

ENTRY TOTAL HEADS.

VARIATION OF TOTAL HEAD WITH COOLING FLOW

19077·S

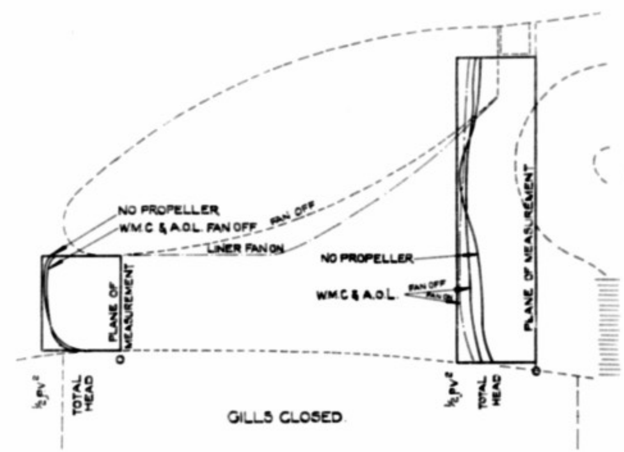


FIG. 9(a)

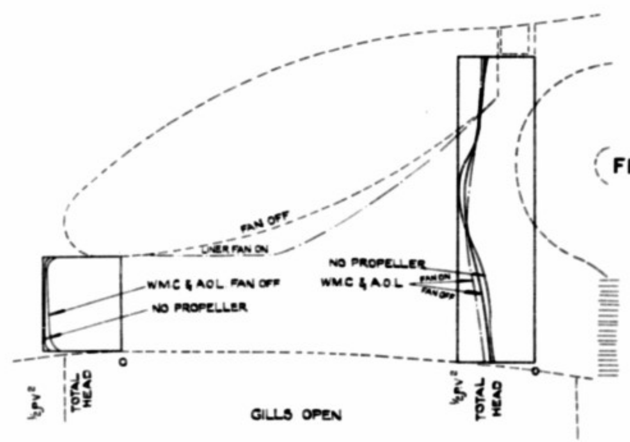
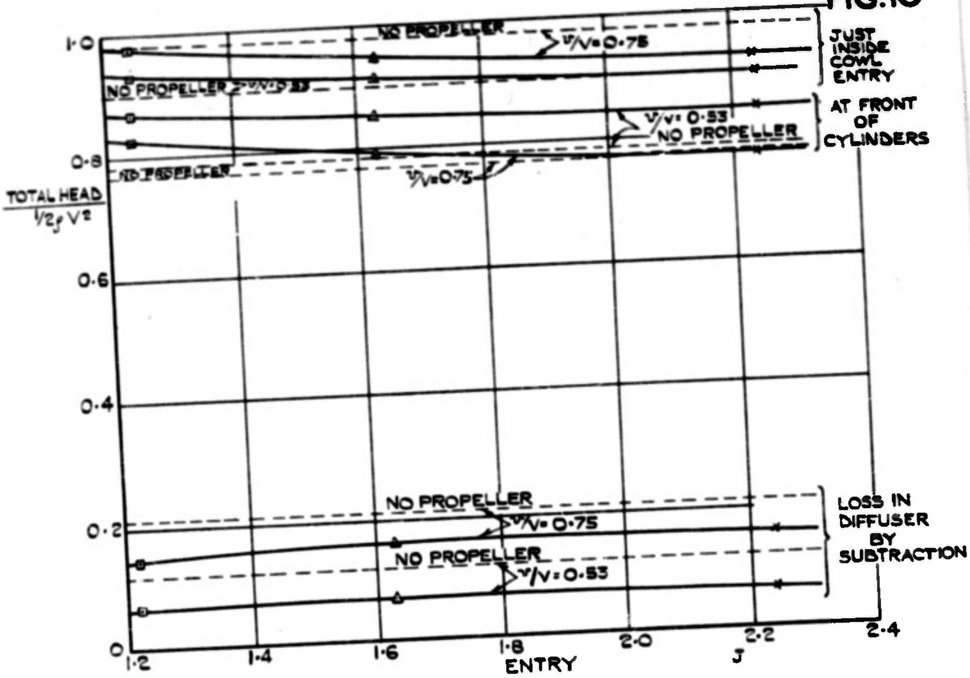


FIG. 9(b)

TOTAL HEAD DISTRIBUTION JUST INSIDE COWL ENTRY AND AT FRONT OF CYLINDERS

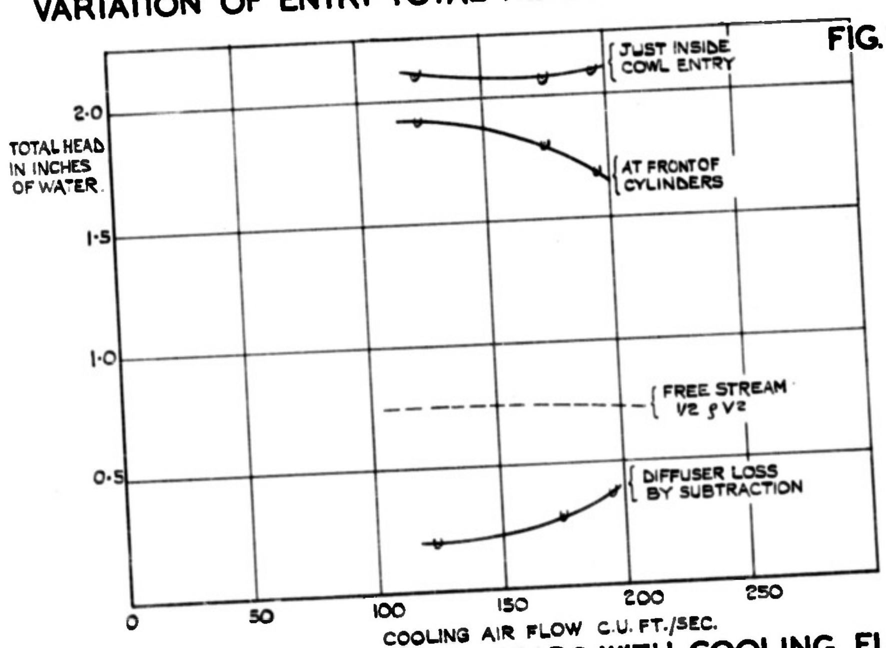
28

FIG.10



VARIATION OF ENTRY TOTAL HEADS WITH J. FAN OFF

FIG.11



VARIATION OF ENTRY TOTAL HEADS WITH COOLING FLOW

GROUND RUNNING 1890 R.P.M. BLADE ANGLE 30°42' FAN OFF

FIG. 12(a) & (b)

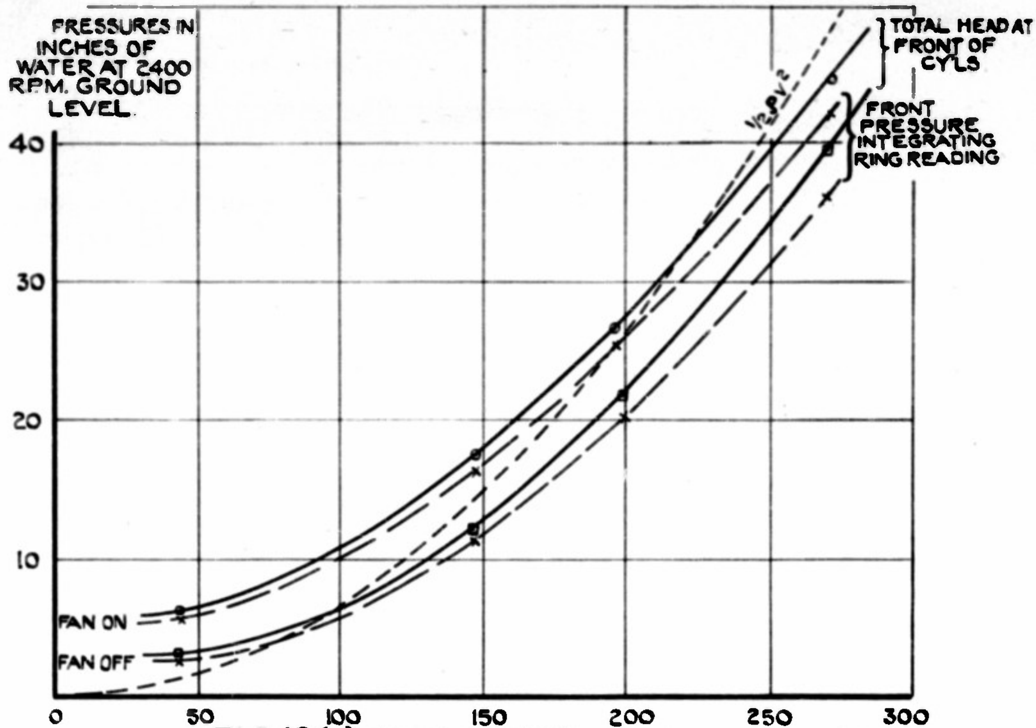


FIG.12(a) GILLS CLOSED

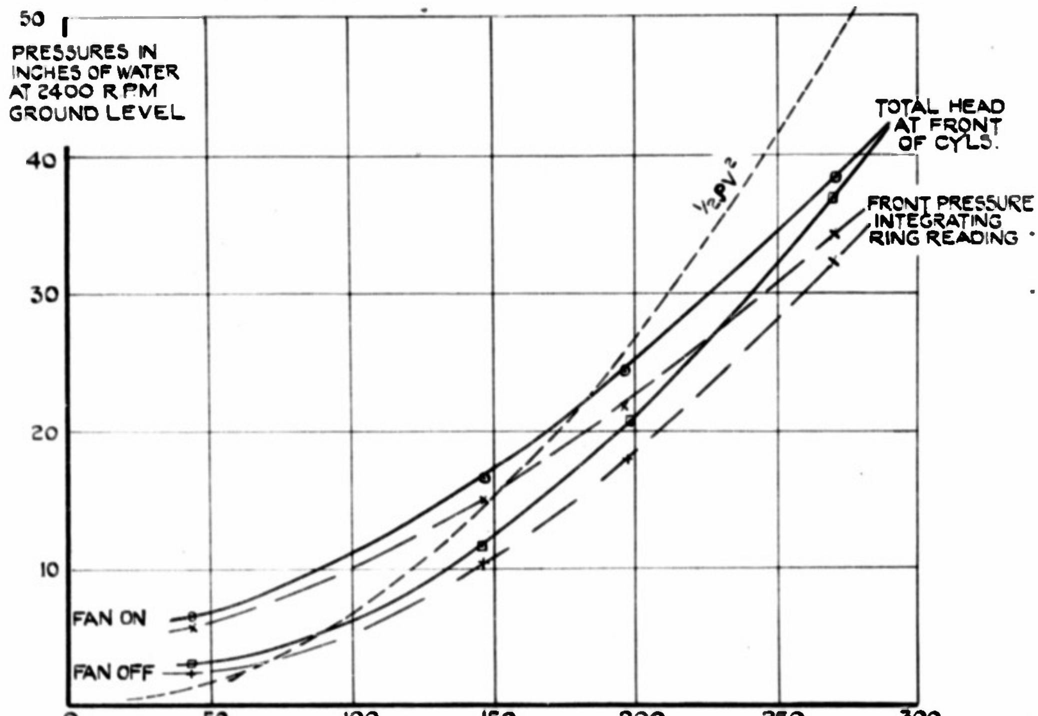


FIG.12(b) GILLS ½ OPEN

VARIATION OF TOTAL HEAD AT THE FRONT OF THE CYLINDERS AND FRONT PRESSURE INTEGRATING RING READING WITH FLIGHT SPEED

No. 19080-5

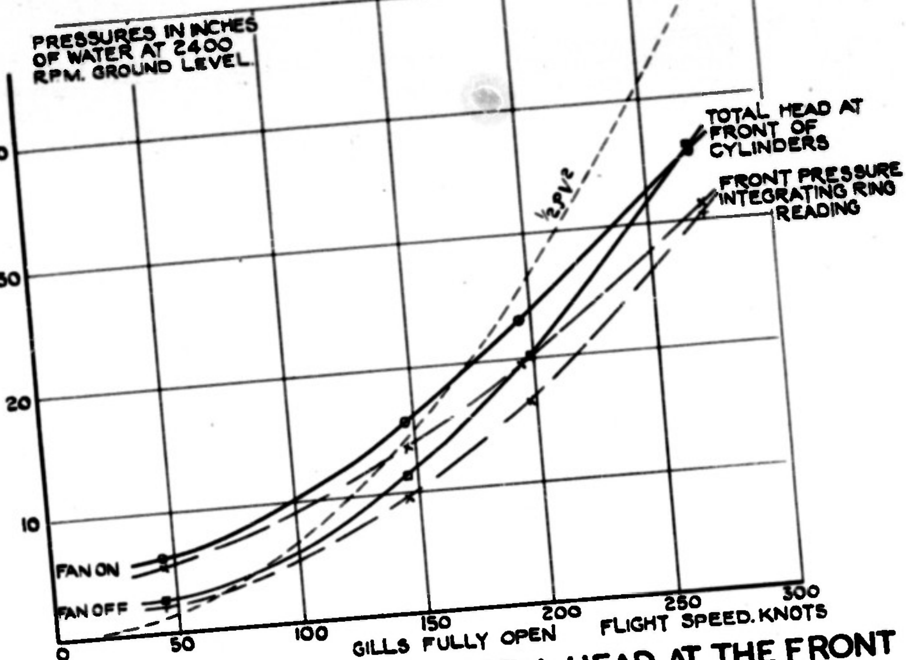


FIG. 12c VARIATION OF TOTAL HEAD AT THE FRONT OF THE CYLINDERS AND FRONT PRESSURE INTEGRATING RING READING WITH FLIGHT SPEED

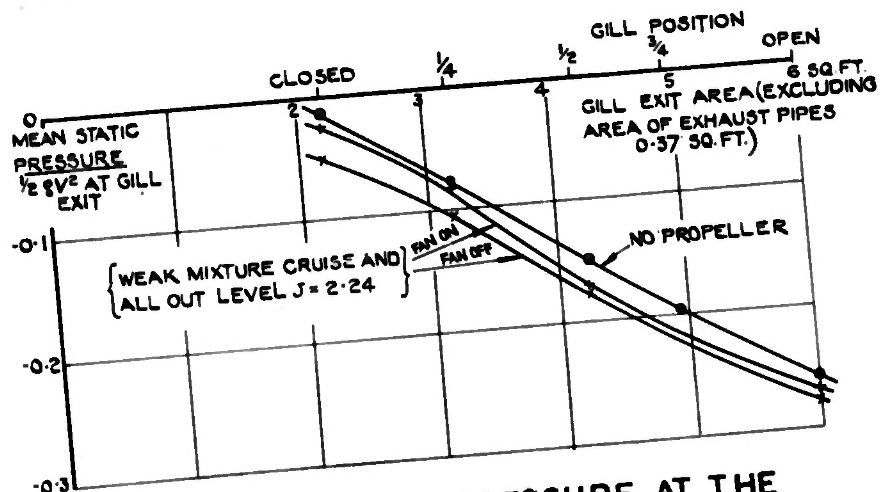


FIG.13 MEAN STATIC PRESSURE AT THE GILL EXIT
VARIATION WITH GILL POSITION

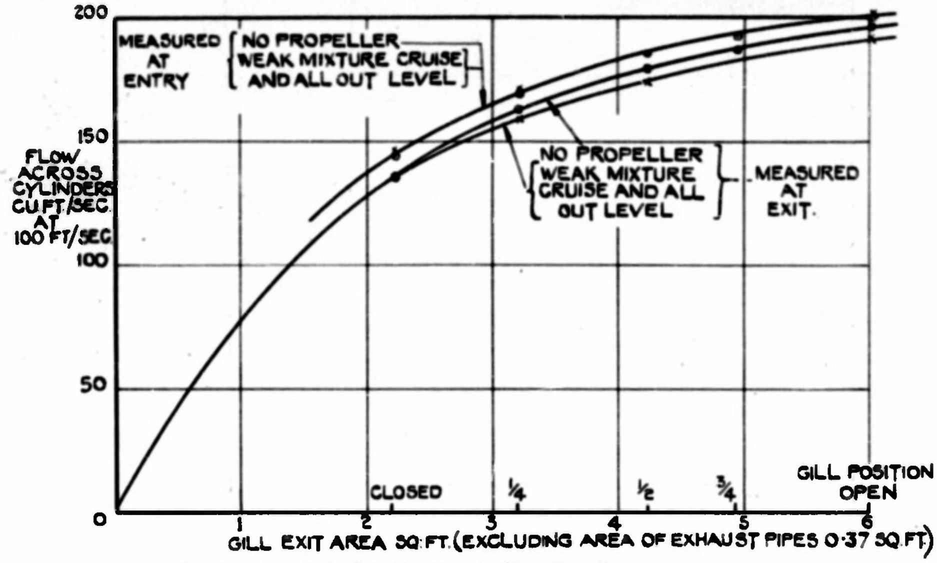


FIG.14 COOLING AIR FLOW
COMPARISON OF MEASUREMENTS AT ENTRY AND EXIT

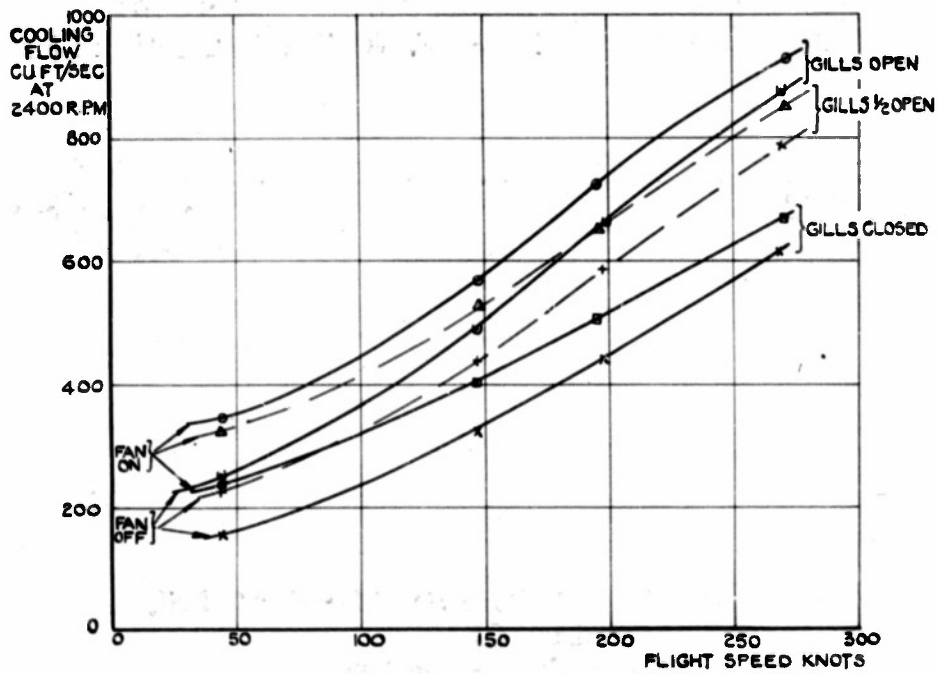


FIG.15 VARIATION OF COOLING AIR FLOW WITH FLIGHT SPEED.

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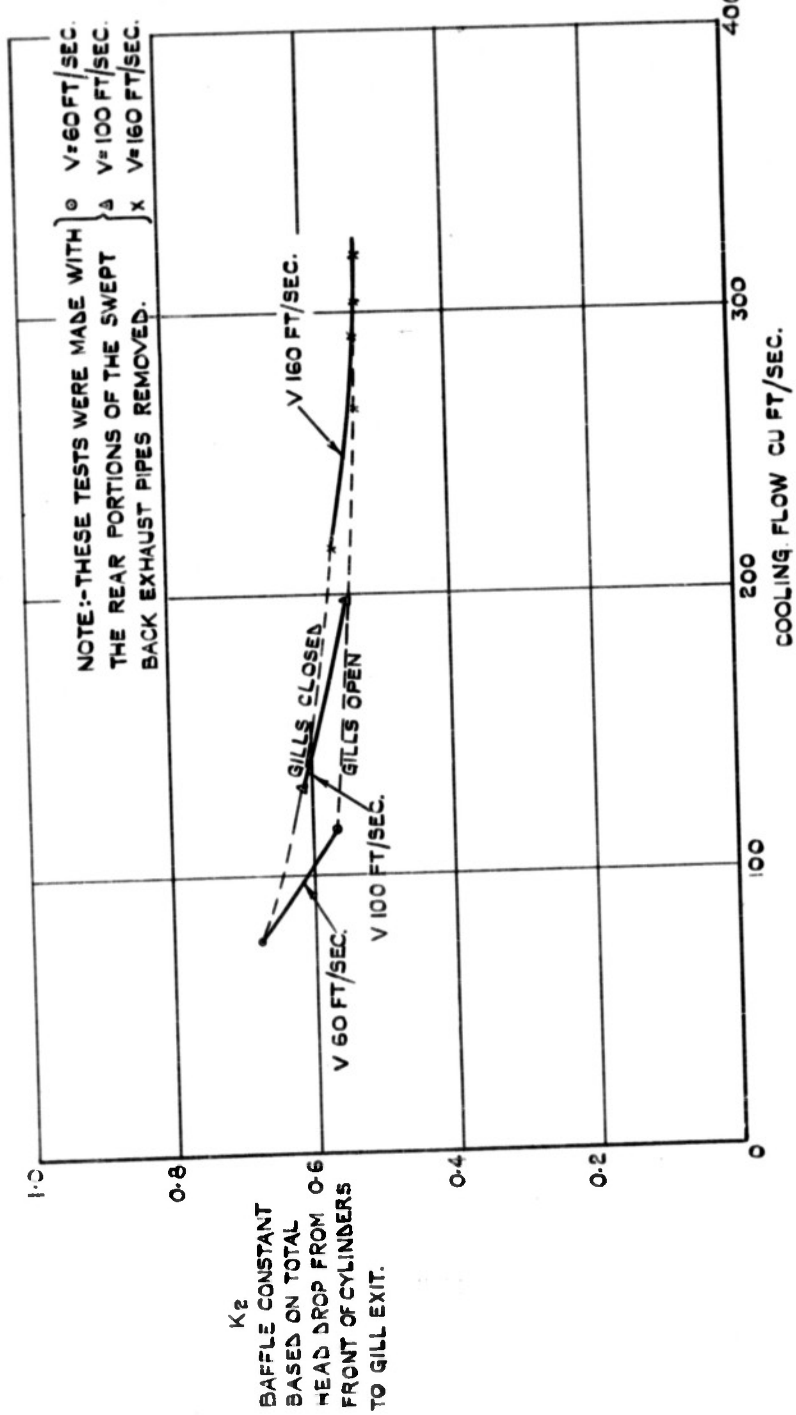
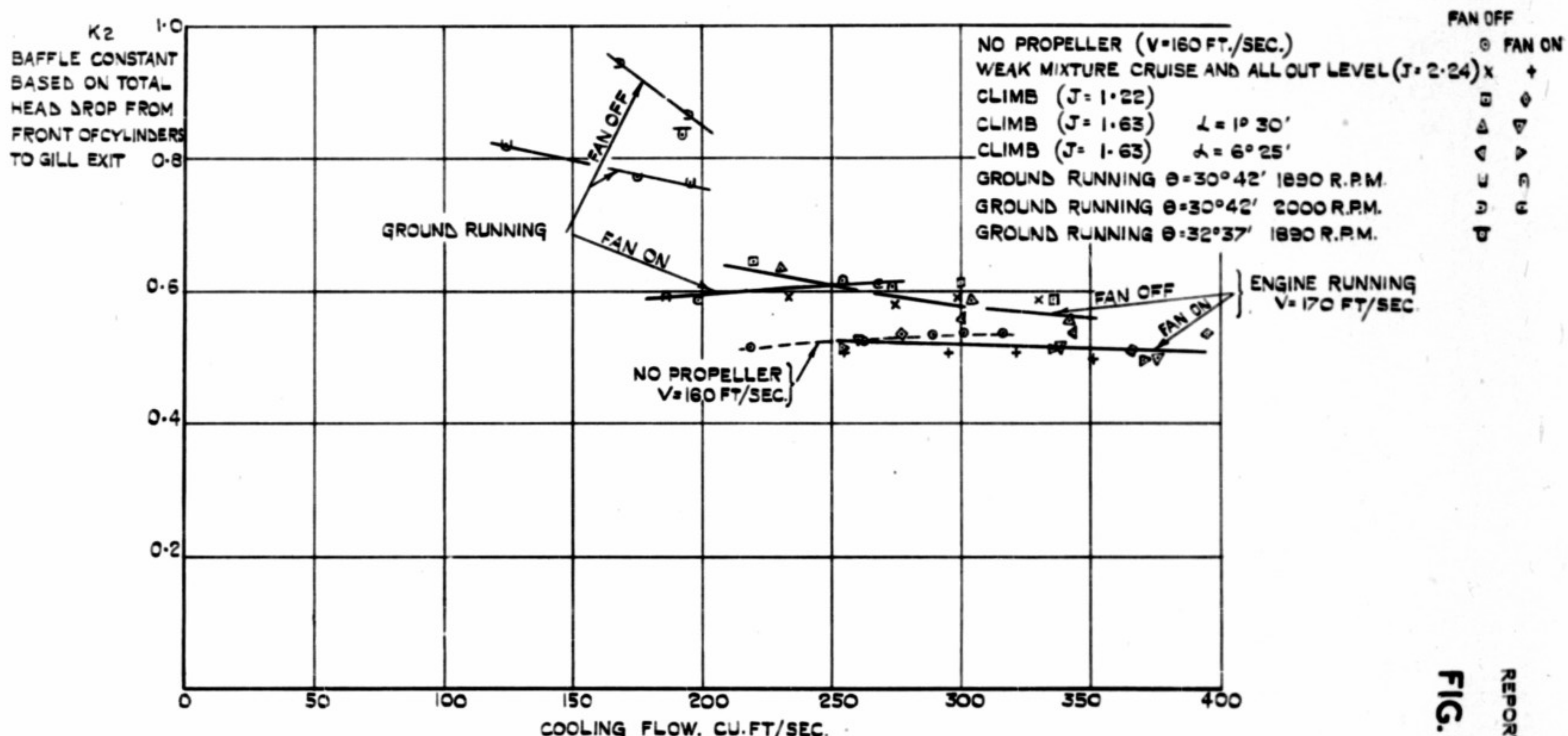
FIG.16



BAFFLE CONSTANTS

(SCALE EFFECT OR EFFECT OF INCREASING FLOW BY INCREASING AIR SPEED)

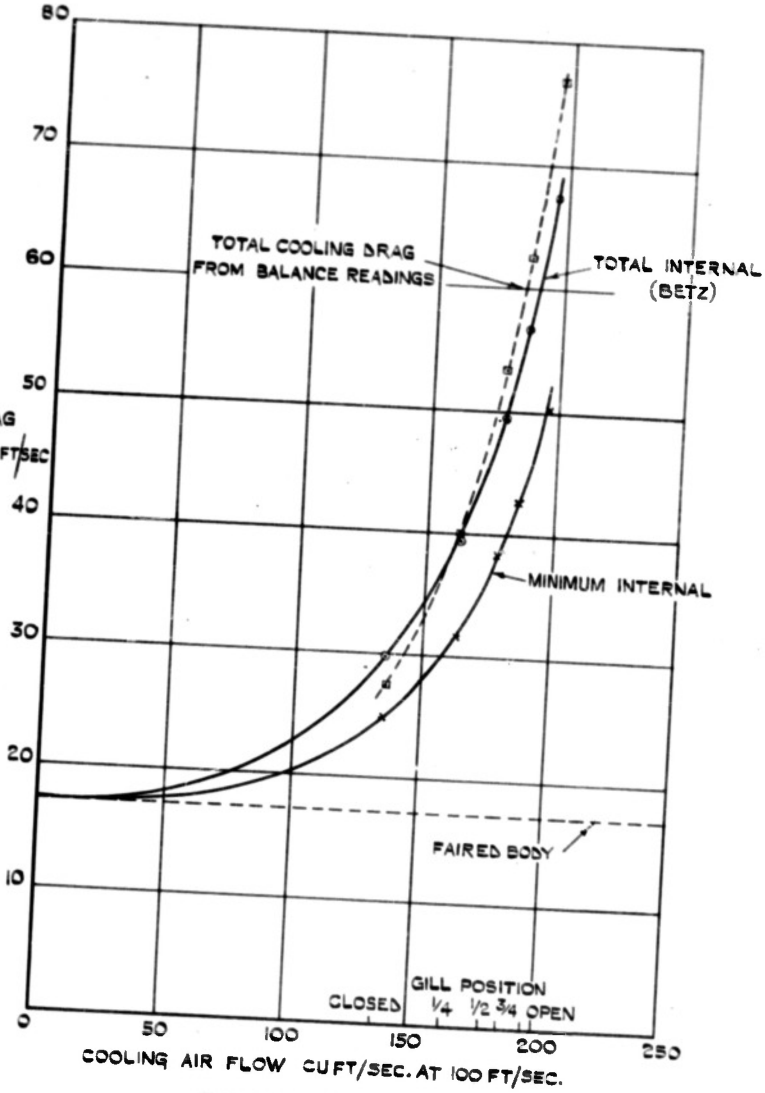
FIG. 17



BAFFLE CONSTANTS

Nº 19084.S

FIG. 18



COOLING DRAG

(NO PROPELLER)

FIG. 19 a & b

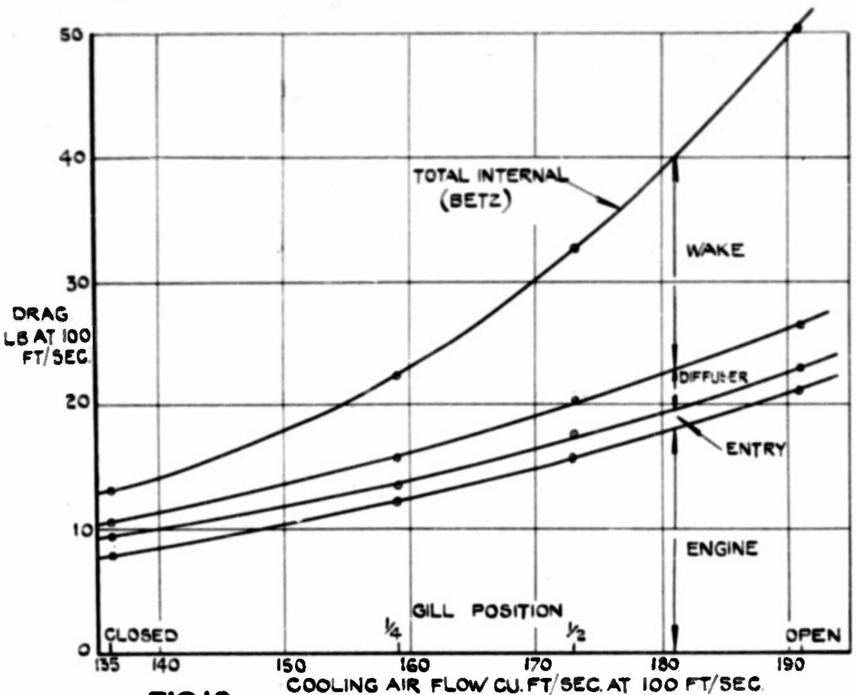


FIG.19 a WEAK MIXTURE CRUISE AND ALL OUT LEVEL FAN OFF

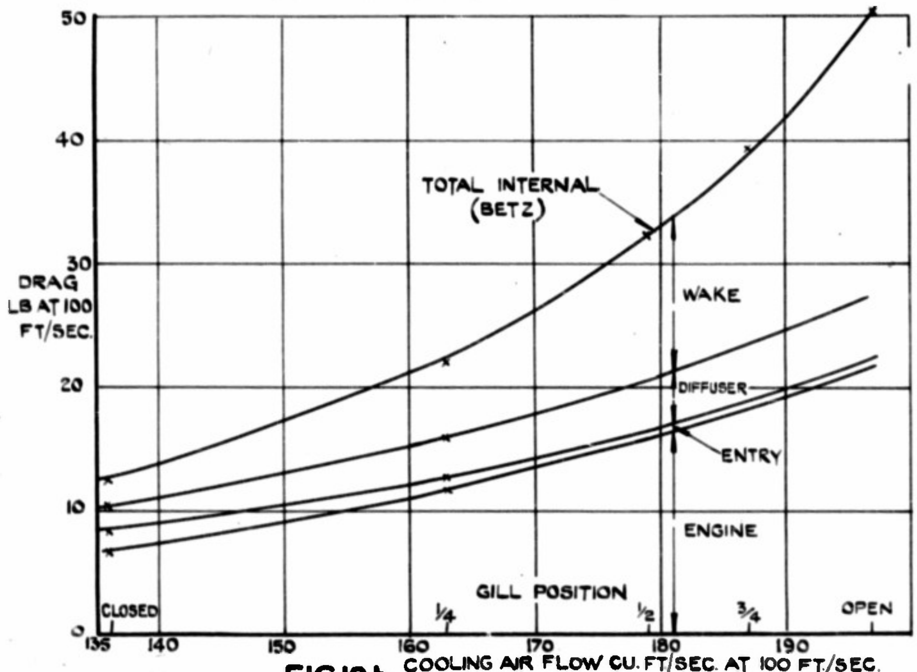
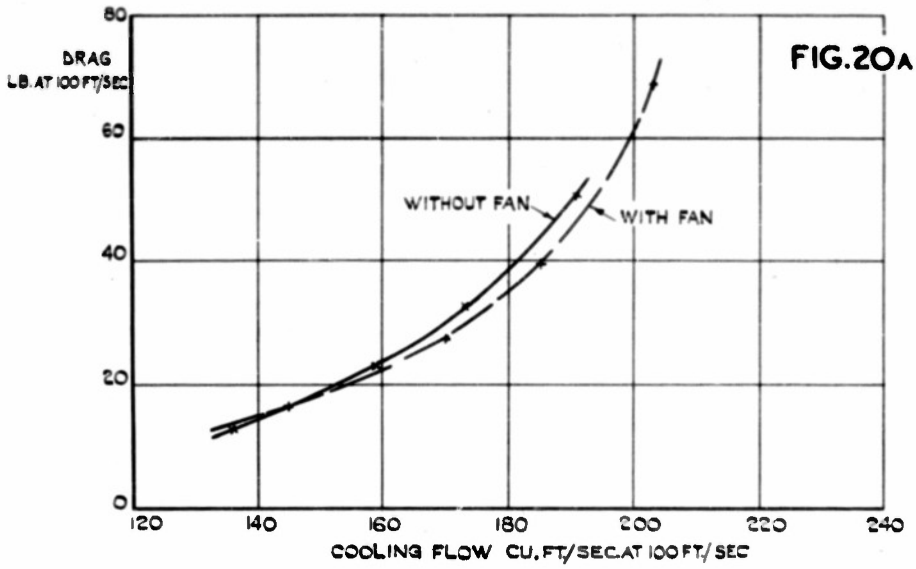


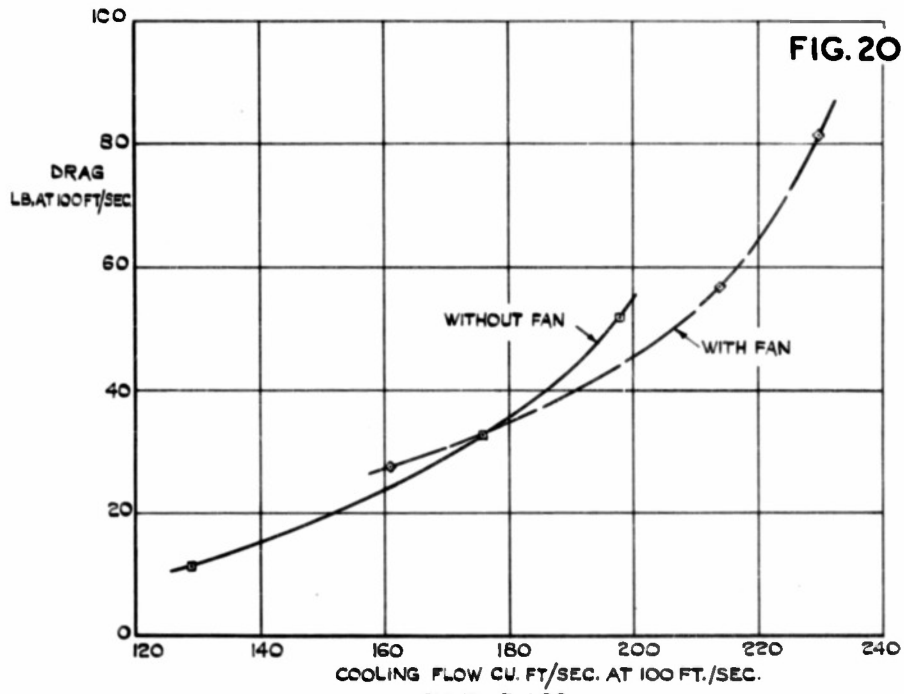
FIG.19 b COOLING AIR FLOW CU. FT/SEC. AT 100 FT/SEC. NO PROPELLER.

INTERNAL DRAG AND DRAG COMPONENTS

Nº 19086 S



WEAK MIXTURE CRUISE AND ALL OUT LEVEL. J = 2·24

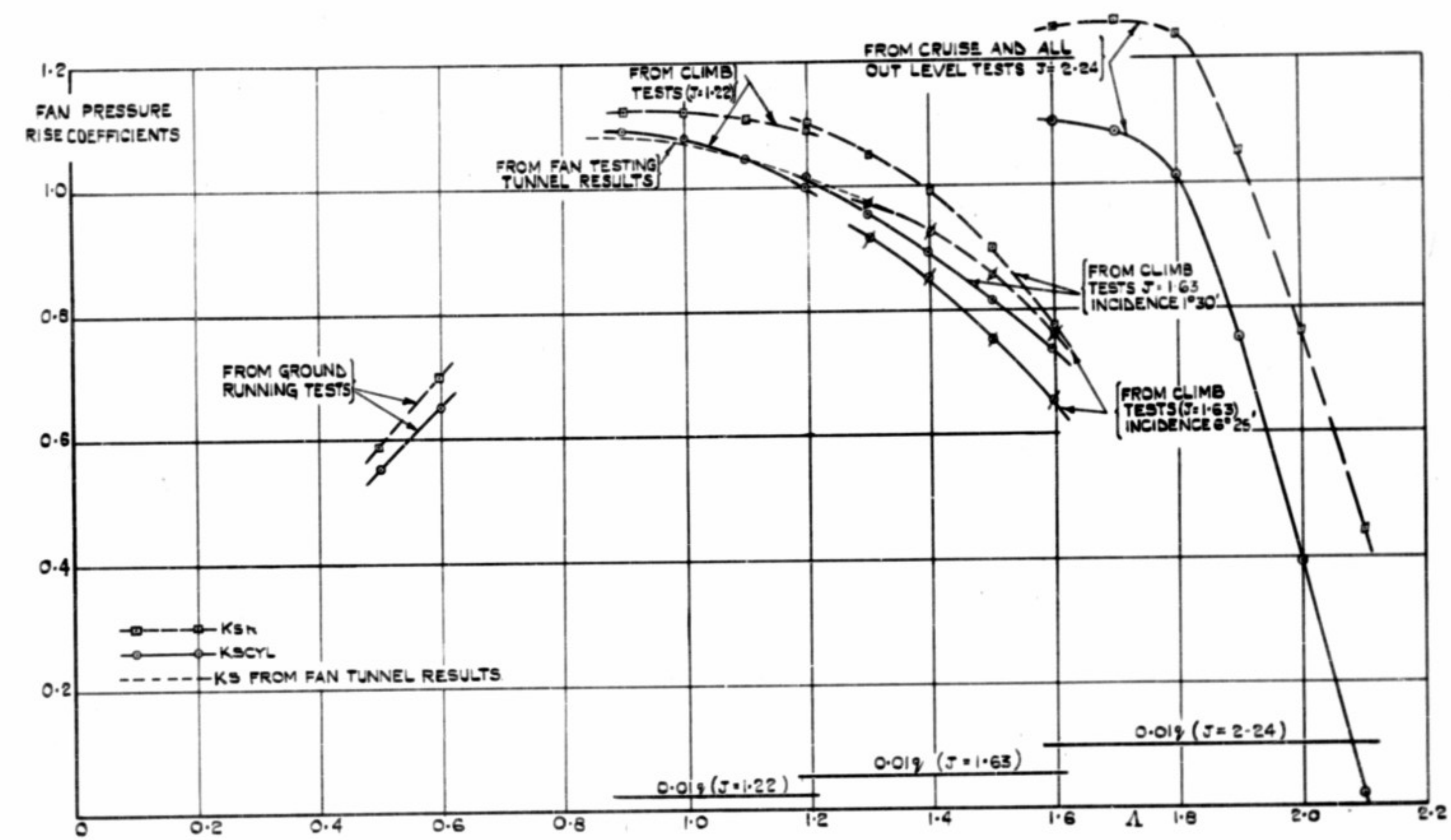


CLIMB. J = 1·22

TOTAL INTERNAL DRAG (BETZ) + EQUIVALENT DRAG DUE TO POWER ABSORBED IN FAN

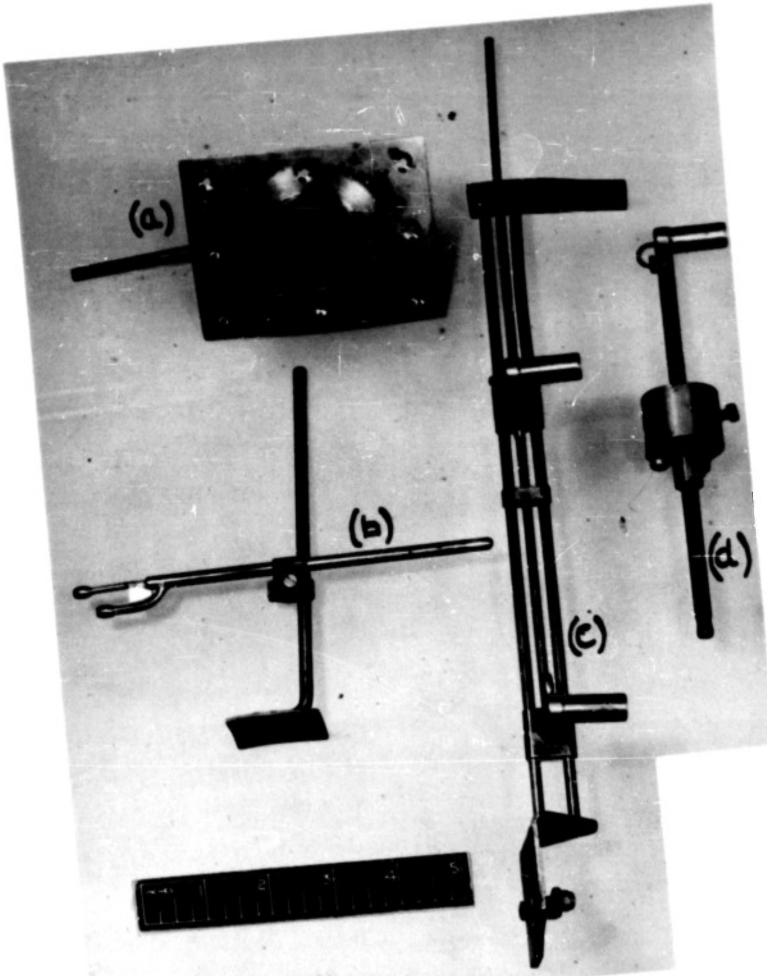
(SEE PARA 4·53)

FIG.21



VARIATION OF FAN PRESSURE RISE COEFFICIENTS WITH FLOW COEFFICIENT Λ (SEE PARA. 4·6)

FIG. 22.



(a) SURFACE STATIC FOR FAN RING; THE RAISED PORTION WITH THE FOUR STATIC HOLES IS PRESSED INTO A CIRCULAR HOLE IN THE FAN RING, FORMING A FLUSH SURFACE.

(b) CONCENTRIC TYPE PITOT AND STATIC TUBES FOR GILL EXIT.

(c) PAIR OF NON-DIRECTIONAL PITOT TUBES FOR RADIAL TRAVERSE AT FRONT OF CYLINDERS.

(d) NON-DIRECTIONAL PITOT TUBE FOR RADIAL TRAVERSE IN COWL ENTRY.

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FIG. 22.

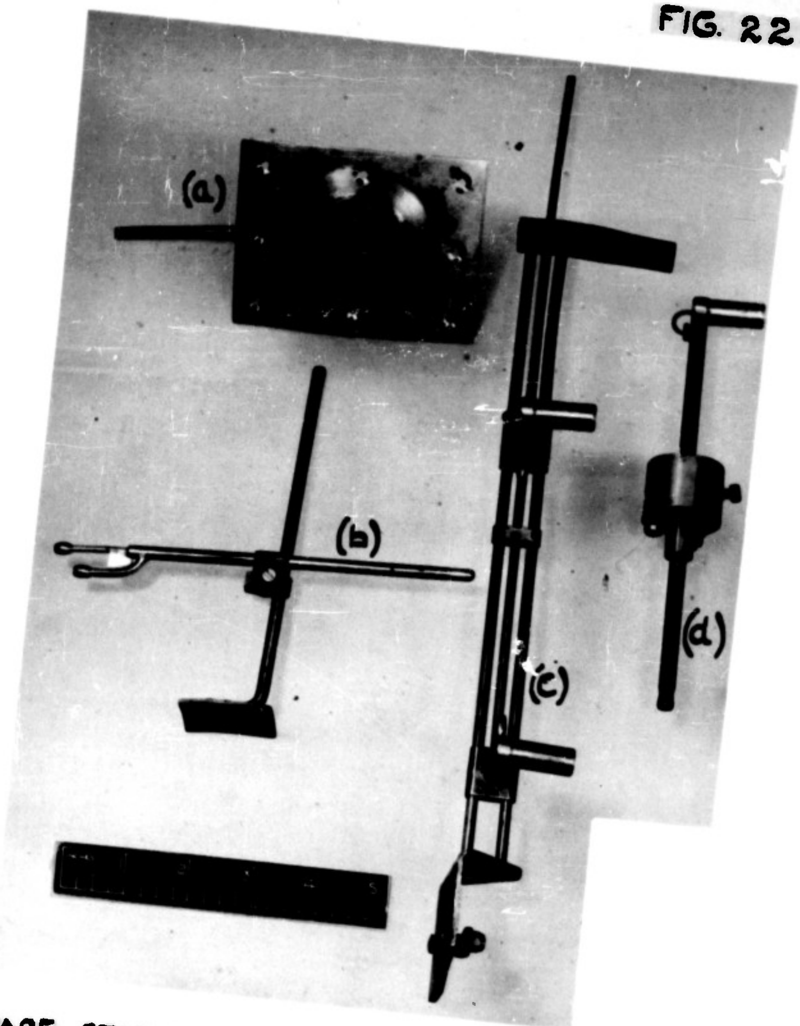

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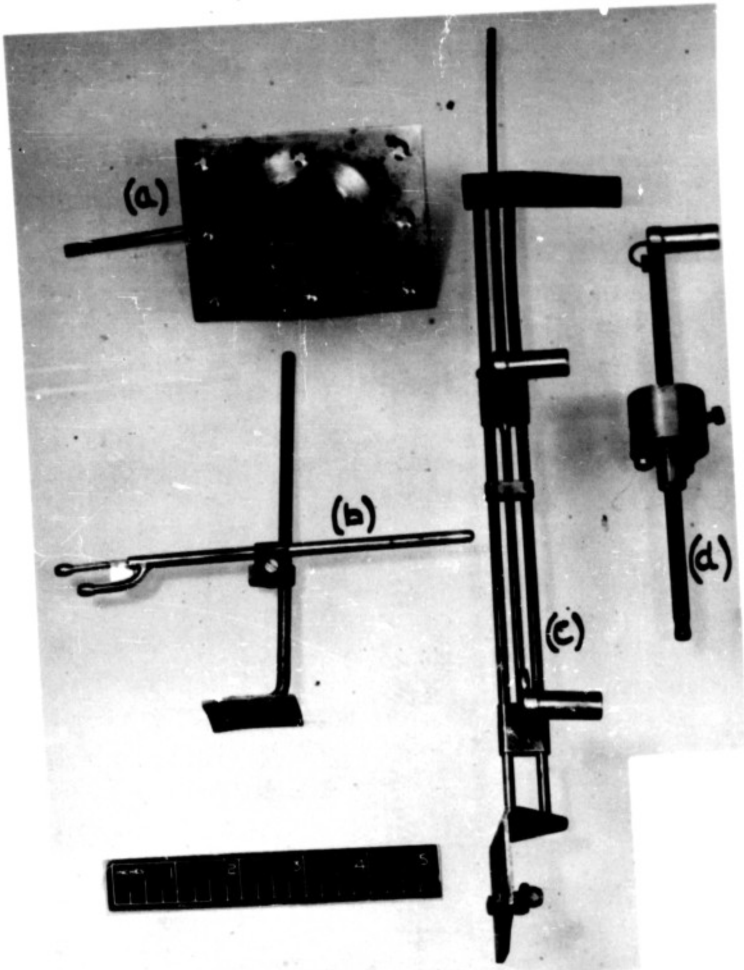
FIG. 22.



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R.A.E. NEG. NO. 70468 /46.

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9015

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TITLE: Drag and Cooling Tests in the 24 ft Wind Tunnel on a Centaurus-Buckingham Wing Nacelle Installation - Part III - Tests with High Speed Cowl Entry -- Tempest Type

AUTHOR(S): Owen, T. B.; Shaw, H.

ORIGINATING AGENCY: Royal Aircraft Establishment, Farnborough, Hants

PUBLISHED BY: (Same)

ATI- 9015

DIVISION (None)

ORIG. AGENCY NO. Aero-2142

PUBLISHING AGENCY NO. (Same)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
July '46	Restr.	Gt. Brit.	Eng.	39	photos, tables, diagrs, graphs

ABSTRACT:

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DIVISION: Aerodynamics (2)

SECTION: Parasitic Components and Interference (7)

ATI SHEET NO.: R-2-7-24

SUBJECT HEADINGS: Nacelles, Engine - Aerodynamics (66075); Nacelles, Engine - Wind tunnel tests (66080)

Air Documents Division, Intelligence Department
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Wright-Patterson Air Force Base
Dayton, Ohio

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EO 10501 dd 5 NOV 1953

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